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WORLD MARITIME UNIVERSITY
MALMOE, SWEDEN

GUIDELINES FOR TECHNICAL SUPERVISION OF SHIP MACHINERY

by
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A paper submitted to the Faculty of the WORLD MARITIME UNIVERSITY in partial satisfaction of the requirement for the award of a

MASTER OF SCIENCE DEGREE
in
MARITIME EDUCATION AND TRAINING
(Marine Engineering)

The contents of this paper refelect my own personal views and are not necessarily endorsed by the university.

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ABSTRACT

The subject of this thesis is to give guidelines for technical supervision of ship machinery in the form of:

- a balanced maintenance scheme, which will be used to bind scheduled maintenance, corrective maintenance and condition-based maintenance in a coherent plan, which should fit within the operating constraints of the vessels of our national fleet. The overall aim is to prevent failure and improve availability.
- bases to ensure that the right amount of spares are held aboard ships.
- Recommending methods to ensure that a good quality of fuel is supplied and handled properly before it is burnt.
- means for organized practical training to build up experience of shore staff and ship's personnel.

ACKNOWLEDGEMENT

Before I mention the individual contributors to this thesis, I acknowledge that all thanks belong to God, who participates in and oversees all human endeavour.

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Special thanks and appreciation are due to all my family here and in Libya for their endless love, encouragement, patience, forgiveness, and prayers which were my real light in the past two hard-working years in this faraway hospitable country.

As in the beginning, I end with my thanks and prayers of gratitude to Almighty God to whom I submit my work and for whose sake I finished it. From God will be the reward.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

Chapter II

Tables & Figures — Page

Chapter III

Section 4.0

Section 5.0

CHAPTER VI

Section 2.0

Section 3.0

CHAPTER I

Introduction

The technical supervision of ship machinery is a process requiring the performance of several functions through the possession of a specific set of professional skill using certain techniques. These functions are planning, organizing, analysing, directing and controlling of the activities required in the process.

Planning: is the process of developing a philosophy of supervising ship machinery. This philosophy is characterized by beliefs, values and attitudes in planning, setting objectives, devising short and long range strategies to achieve these objectives.

Organizing: is the process of achieving coordinated effort, through the creation of a structure of tasks, and execution of sequences as a function of time.

Controlling: is the process of evaluating the actual performance against established standards, and correcting deviations.

Analysing: is the process of interpreting causes of deviation, based on subjective or objective data, through which standards are modified.

Directing: is the process of leading, advising, and motivating through effective methods of communication.

The technical supervision in a very real sense has the role of the keystone, if its position lies at the critical stress area, i.e between the standards and the actual conditions. Therefore, employing appropriate standards and getting continous feedback are necessary, if progress toward goal accomplishment is to be achieved.

I intend to illustrate those factors that contribute in the technical supervision process, within the limit of my objectives which will be covered in the following chapters.

1.0 Objectives

To illustrate maintenance systems technique that can be used to achieve appropriate ship machinery availability which should fulfill maker recommendations, classification society and administration requirements, to ensure the highest level of safety and optimum operational performance.

This will include the following:

1. Necessity maintenance, which must be done to enable ships to conform to the standards of the classification society and administration.

2. Optimization maintenance concerning the efficiency of machinery such as minimum fuel and lubricant consumption, which spares are used. In addition break downs are minimised.

3. Formulation of work plans and provision of control to achieve the desired results, i.e the more maintenance is planned and the more information is available about the state of ship machinery, the less guesswork there will be in the planning of maintenance tasks.

4. Flexibility, that is to say, by employing performance monitoring and faults diagnostic equipment, the machinery condition is assessed objectively. In this way unnecessary maintenance of machinery when it is performing well can be avoided.

5. Development and operation of spares control system.

6. Fuel handling in terms of operating practice with a fuel system such as fuel treatment, segregation, analysis and quality control.

2.0 The present state of the technical supervision of ship machinery can be described in brief as follows.

1. Functions: to follow ships and machinery, specially the critical ones, to arrange to supply spares, stores, and lubricants, and to arrange for repairs.

2. Activities: are associated with the functions carried out between the superintendent engineers and the ship's staff. From time to time their work is supplemented by assistance from outside experts and special facilities, such as drydocks, shipyards, and engine makers. In addition both shore and shipboard staff work closely with the classification society and administration.

3. Maintenance system: corrective maintenance is the most dominant system used on board ships, except for main engines and auxiliary engines where maintenance is almost always based on running hours.

The key to machinery maintenance is usually the chief engineer's attitude, as it almost always depends on the shipboard staff initiative. Since there is no clear maintenance system in our shipping company the programme to be followed will reflect the chief engineer's philosophy. If a relief is sent in, the programme will change to reflect the new chief engineer's experience and whims.
Generally he will use his common sense to identify new problems, and concentrate on those areas from which most

problems will arise. However, without a more structured approach, it is likely that other potential problem areas will not be addressed.

4. Data collection: there are a number of reports required by the technical department during each complete voyage. These reports are listed below:

a. Engineers log abstracts, reported on a standard form. It is not totally utilized.

b. Voyage reports, comprising the performance of machinery, remedies and recommendations to avoid future break downs, delays in ports due to technical reasons, repairs carried out by shore based work shops, crew behaviour and performance. These reports are worked out by the chief engineer based on his knowledge and experience.

c. Fuel and lubrication, oil statement, listed on a standard form. Its capacity is limited to quantity consumed, received and remaining during the complete voyage.

d. Boiler and cooling water analysis, listed on a standard form.

e. Voyage shipboard work undertaken, there is no standard form used for this report. It is left to the chief engineer's knowledge and experience.

f. C S M items and surveys carried out.

g. Spare parts used.

h. Stores and supplies received.

i. Guarantee claims.

j. Spares requisition.

5. Trend analysis and extrapolation is limited.

CHAPTER II

One of the major goals of maintenance systems is to minimize causes of failure, failure rate and its consequences in order to keep machinery operating safely and performing efficiently. Thus, prior to choosing a maintenance system it is necessary to consider the following.

1.0 Failure nature

Failure is commonly defined as break down. A unit or part may suffer a failure initially or during service for a variety of reasons. Some of these reasons are;

- it does not perform the required functions;
- it does not give the specified output;
- it wears out before its designed working life;
- it breaks down during service.

Experience indicated that the cause of failure is usually one or a combination of certain features that increase the cyclic loading or reduce the endurance of the part to a level at which initial or service failure is inevitable. Many failures stem from two principal faults; neglect to take account of significant cyclic loading in the design and neglect to take account of defect features that reduce radically the fatigue strength of parts.

Most faults, however, are caused by ;

- neglect of cyclic service loading;
- resonant vibrations and torsional load;
- increase of service cyclic loading due to wear or maloperation;
- material defect;
- unsatisfactory weld and surface deposits; or
- corrosion and fretting.(1)

2.0 Failure models

With respect to an item's life cycle, we can distinguish between three main models of failure.

2.1 Chance failure (purely random)

It is the experience with a very wide range of components and items that, under their normal operational conditions and during their normal operating life, they do not reach a point of wear out failure at some likely time that could be called "old-age". On the contrary, a given item is as likely to fail in a given week shortly after installation or many months later. In short, the probability of failure is constant and independent of running time; the item is always effectively as good as new. Very often such behaviour indicates that the cause of failure is external to the item.

A failure feature of this type indicates that the failure mechanism is process-related to maloperation or poor design (2).

A simplified model of such a failure is indicated by Figure (1)

2.2 Running in failure (an early failure model)

It is the experience with many types of equipment that the probability of failure is found to be much higher during the period immediately following installation or maintenance than during its subsequent useful life.

Some of the items are manufactured or installed with built-in defects which show up during the running-in stages. Those that survive this stage without failure were without such defects to begin with; they go on to exhibit the sort of time-dependent failure probability (the equipment is not improving with age, some items merely start off with a better chance of survival than others).

A failure feature of this type indicates that the failure mechanism is manufacture, assembly, or recondition-related. (2)

Figure (2,3) illustrates the failure mechanism, in the case of design it is with anticipated wear, and without anticipated wear.

2.3 Age dependent failure (wear out failure)

The age dependent failure is caused by a critical failure which is developed from a defect due to some faults during operation. This defect is denoted as a primary failure. It is defined as an occurance or circumstance which worsen the deterioration rate considerably.

Thus age-dependent failure consists of two main elements:

- the probability for a defect or a primary failure to arise; and
- the time involved for this defect to develop to a critical failure. (3)

Figure (4) illustrates the notation primary failure and developing time (TD) to a critical failure when the design is with unexpected deterioration. Figure (5) illustrates the notation primary failure and developing time (TD) to a critical failure when the design is with anticipated deterioration due to wear out.

3.0 Failure rate during a single item life cycle. Many pieces of mechanical equipment demonstrate a drastic change in failure rate throughout their life as is shown in Figure (6). This curve is known for obvious reasons as the "bath tub curve". It consists of three failure rates.

The first part is the decreasing failure rate. The machinery is quite new and teething problems are occurring due to faulty installation, or poor manufacturing and maintenance. However, as these teething problems are rectified, the machinery settles down in a frequency of failure.

The second part represents the period at which the machinery and components are relatively new.

Under perfect working condition it will be exposed to chance failure. If this is not the case failure may take place in the form of primary failure that will develop to take the form of critical failure.

The middle range is sometimes called the useful life of a single item life cycle, during which the preventive maintenance techniques offer the most benefit.

The final part; failure rate increases due to the increasing occurence of wear out. In most of the cases the failure is made up of an element of random failure and element of wear out failure (4.5).

4.0 Failure prediction

4.1 Failure statistic

The main reason for using failure statistics is to know the mean time between failure (MTBF) probabilistic variable.
The accuracy of such a probabilistic variable depends on the amount, precision, and dispersion of data collected during a life cycle of items that should have the same design specification and operating conditions.
The above mentioned requirements for accuracy of probabilistic variable are quite difficult to collect in a shipping company with a limited number of ships due to the fact that a small number of items that have the same design specification are available under the same operating condition. A long time is required to collect a good amount of data.

With reference to failure models and their distribution functions, such as exponential distribution. This distribution is associated with early life failures during running-in period. There is no scope for predicting early failures statistically because of their nature. In the case of rectangular distribution the cause of chance failure is a combination of random circumstances. It is not possible in any rational way to predict the time at which such events will occur.

In the case of normal distribution which is used as a model to describe wear out failures in a mechanical system, such failures are the result of time dependent mechanisms such as corrosion, deterioration, or mechanical wear.

Thus the scope of predicting failure, statistically, without having a resonable amount of data with a good precision and dispersion during its collection, is quite limited.

However, it is necessary to rely on maker recommendations and experience in implementing scheduled maintenance, adding to that the use of condition monitoring techniques i.e. performance monitoring, samples analysis and trend analysis.

The use of diagnostic technique claimed enough reliability to predict and detect failure, except when failure rate is constant (chance failure).

In this case the only way to predict failure is by functional testing or non-destructive testing.

Functional testing is mostly applied to check system function before use. This means that the failure still exists but the consequences might be less.

Non-destructive testing is more commonly used to predict the causes of this failure, exclusively for material defects.

4.2 Choice of monitoring approach

For any particular failure mode the choice of monitoring approach rests on the relative costs of the feasible operations, the nature of the potential failure mode, the criticality of the equipment itself, and the lead time required.

1. The nature of the potential failure mode; refer to section 1.0, 2.0). The nature of failure mode is very important to know in order to use the right type of monitoring technique (the right sensors) that will predict the failure occurence within the required lead time.

2. Criticality
A piece of equipment is "critical" if the function of the ship's machinery depends upon it, e.g. an active component. By an active component is meant energy transforming components such as pumps, fans, electric motors, generators, combustion engine, turbine and boilers.

The criticality nature of this equipment may be reduced by providing redundancy in the form of a system or component ability to maintain or restore its function when a failure has occurred. In other words if a given component fails, its function is taken over by another component. A stand by pump is a typical example of redundancy.

Due to economic and space constraints in some cases redundancy cannot be arranged, e.g. main engine or boiler, whereas corrective or predictive maintenance which entails taking a critical equipment out of service puts the plant out of action, a lead time is required which is sufficient to allow the preventive maintenance always to be undertaken in port. For the redundant equipment, this is less important. (3,6)

3. Failure lead time
Lead time is defined as the extent in time to which failure can be predicted.
Lead time is perhaps the most important variable involved in

the identification of suitable condition monitoring methods. It must be at least equal to the time needed to plan and arrange the work together with safety margin to cater for inaccuracy in the failure prediction. Because of this need the lead time must be as large as possible and must exceed the decision response time.

Essentially the above mentioned is the required function of condition monitoring to predict the point at which a failure will occur early enough for the necessary preventive maintenance to be carried out at the next convenient opportunity.

In general a failure which can be rectified at sea by the crew is less important in terms of lead time than one which can only be rectified in port. This holds for both critical and redundant equipment. (6)

5.0 Failure Prevention.

5.1 Selection of maintenance systems.

As with all forms of preventive maintenance, the objective of condition monitoring and condition based maintenance is to reduce the risk of failure.

Preventive maintenance can achieve a great deal in this respect, but the problem is to know where to stop.

It is suggested that the real criterion is cost, and that the optimum is reached when the sum of the costs of preventive maintenance and corrective maintenance, together with associated consequential costs, are at a minimum.

The precise relationship between maintenance cost and failure risk is difficult to arrive at, but if the best possible monitoring system is to be decided, it is necessary to explore their relationship for the whole plant.

Where adequate historical maintenance and cost records are available, analysis of these should do much to identify the equipment which gives rise to large costs of maintenance and off-hire and to identify the failure modes responsible. If such records are not available, an analytical process, using whatever data can be provided by manufacturers or classification society, must be substituted.

In pursuing a balanced maintenance system, it is therefore necessary to design a scheme which will unite scheduled maintenance, corrective maintenance and condition based maintenance in a coherent plan fitted within the operating constraints of the vessel. The overall aim must be to prevent failure and improve the availability. (6)

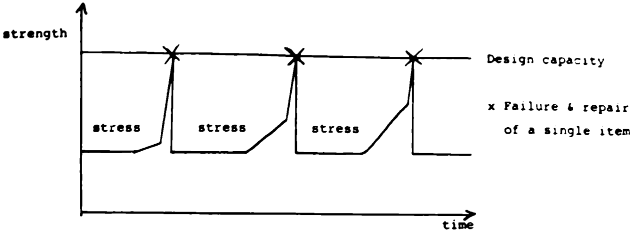
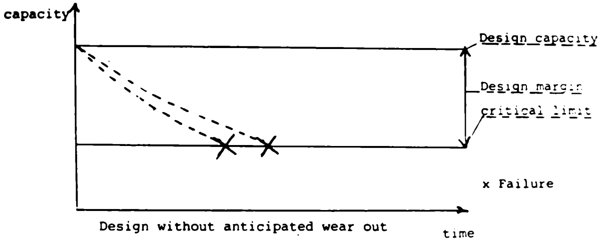
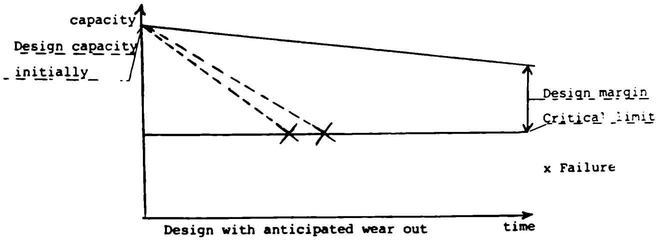


Figure (1) Chance failure mechanism



Design without anticipated wear out

Figure (2) Running in failure mechanism



Design with anticipated wear out

Figure (3) Running in failure mechanism

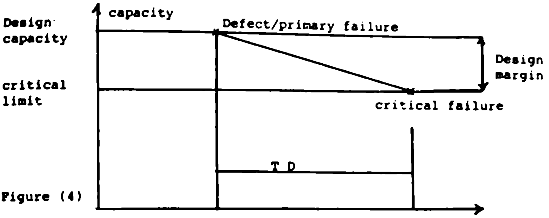


Figure (4)

Design without anticipated wear out

Age dependent failure mechanism

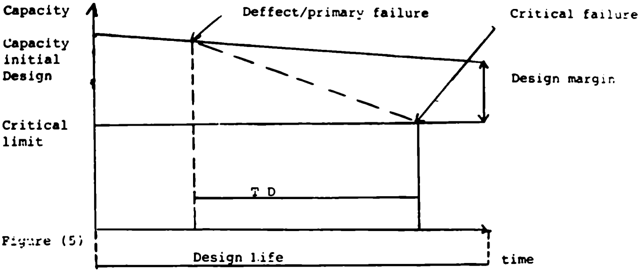
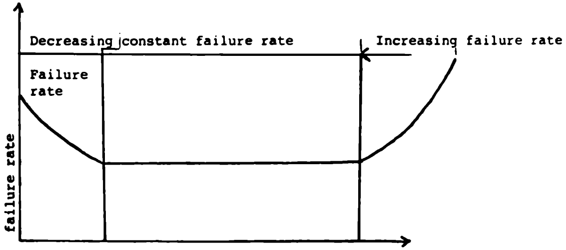


Figure (5)

Age dependent failure mechanism. Design with anticipated wear out

Figure 6



Life cycle of single item

CHAPTER III

1.0 Maintenance concept

The maintenance concept is defined as the combination of all technical and corresponding administrative actions intended to restore an item to a state in which it can perform its required function.

2.0 Corrective maintenance

It is defined as all those activities, the aims of which are to correct faults that have already occurred, i.e restore broken down machinery to a satisfactory condition.
Corrective maintenance action can be planned, which is usually carried out as reconditioning parts of machinery before it breaks down, or unplanned, which is usually regarded as repair. It requires skilled staff and tools, some spare parts stock in particular for the fraction of cases in which repair is economically or technically not feasible.
Corrective maintenance is often necessitated by the fact that the failures turn up at random.

3.0 Planned maintenance system

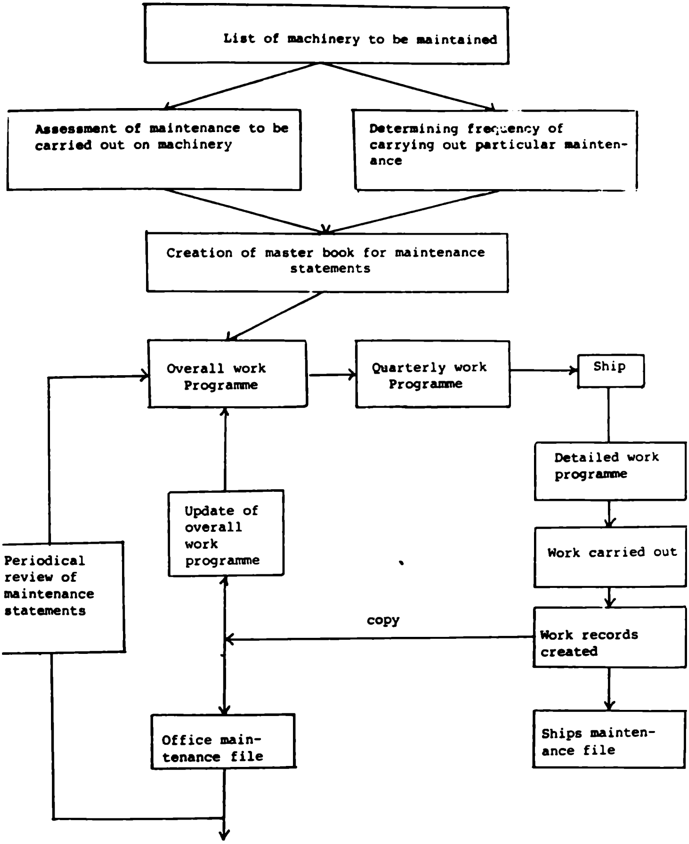
A planned maintenance system divides machinery maintenance into weekly, monthly, semi-annual, annual, biennial and quantennial. It aims to reduce unscheduled repair-work and to improve ship machinery reliability and availability for operation.

3.1 Criteria of a well planned maintenance system.

- It must be comprehensive.
- It must be flexible to allow unscheduled repairs and changes of periodicity.
- It must be simple to operate.

- It must include spare parts and necessary stores management.
- It must permit the building up of a continous picture of all equipment.
- It must provide feedback information about costs to the operators

3.2 Planned maintenance overall operating method. (5)



3.3 Basic element required in planned maintenance

3.3.1 Identification of machinery which deserves to be included in the planned maintenance system is based on;

- items/systems criticality.
- machinery continous survey.

3.3.2 Assessment of what maintenance is to be carried out. It should be based on maker recommendations and operating experience with similar equipment.
Thus it is necessary to make sure that detailed work instruction for each maintenance task is included in the instruction manual for each item;if not, such instruction should be prepared.
It is necessary to make sure that safety precautions, special tools required, spares needed, number of working people and time required to execute the job is mentioned in each maintenance task instruction.

3.3.3 Determining frequency of carrying out particular maintenance tasks
In order to determine frequency of carrying out a successive maintenance operation, a number of factors in addition to those of technical nature (maker recommendations) should be considered.

These factors are;

A. Survey cycle maximum length; in most cases classification societies require presentation of surveyable items in a dismantled condition. It will be reasonable to assume that survey will be completed at the same time as a planned major overhaul.
Since the classification societies demand that the period between surveys does not exceed 60 months, then, within reason surveys can be carried out at lesser intervals than 60 months.

These will give some latitude in determination of overhaul frequency.

B. Relationship between calender time and running hours; it is desirable for the head office to have the overall control of the maintenance system, and this control is more readily achieved by using calender time criteria. Therefore, some conversion from running hours to calender time is necessary, e.g for main engine items they are readily achieved by considering the utilisation of the vessel itself. For items where more than one unit is fitted for a given function (auxiliaries) this becomes more difficult. The use of a regular changeover policy will assist in creating a reasonably effective conversion to calender time.
For items which do not operate continuously such as main air compressors, service pumps, etc., the conversion will be possible by the use of operating experience, or running hours counters.

C. Number of units in each set of machine; the maintenance work required on a given system will be the same, irrespective of the number of machines serving the system.
It will be helpful in each given maintenance task to include all the work demanded for the lesser tasks.

Periods between overhauls for those items functioning in parallel can be extended if those items are not required to function in parallel continously.

D. Time intervals required for the control function; the aim of the control is to leave planning of the maintenance programme (strategic) in the hands of head office personnel and the detailed maintenance programme (tactical) in the hands of the ship's staff.
To achieve this aim it is necessary that office work schedules

are not created too frequently. The ship's staff is able to take account of local conditions (e.g port requirements on immobilisation of main engine) in carrying out the work schedules. Therefore, the minimum time interval for the control function will be ascertained in the order of one to two months taking into consideration ship's routing. (5)

3.4 Creation of a master book for maintenance statements

A. Indexing is the main problem in creating master books for maintenance statements. It should be designed to allow a speedy sort of information and to allow condensed imformation transfer between ships and office. Each item to be maintained should retain a unique number. This will ease the work of planning, recording and analysing.

B. Numbering system: A maintenance system requires a systematic arrangement in order to fulfill its objectives.
All items should be logically grouped and identified by using letters and a decimal coding method, based on certain numbers of main groups with a certain number of digits for each item number.

C. It is necessary to adopt formal rules governing the numbering of components by location whereas all engine units should be numbered with respect to the classification society system.
Equipment in general should be numbered forward to aft, port to starboard (this would include inboard and outboard) upper to lower. (5)

3.5 Creation and implementation of work schedule

A.The overall work programme should be based upon survey cycle length required by classification societies. It should detail inspection, minor overhaul, major overhaul, and survey items that should be carried out during the cycle with their corresponding dates.

B. Through overall work programme the quarterly work programme can be readily extracted and listed for ships use.
Maintenance work required in a given period (e.g quarterly) should be roughly balanced to give reasonably constant work loads for the ship's staff.
The instruction list would include a list of item code numbers maintenance tasks to be carried out for all equipment during a quarter of whole a cycle. (5)

3.6 Creation of reporting procedure

The aim of creating a reporting procedure is:

A. to provide data of operating control for head office;
B. to provide information to the ship's staff of past maintenance history for particular pieces of equipment;
C. to provide means of continuously updating maintenance schedules in the light of operating experience.

It should be remembered that the weakest link in the maintenance control chain is the method by which information is transferred; therefore, it is essential that the design of paperwork should be based on ease of completion and comprehensiveness in its coverage.
All measured parameters such as wear rates, running hours, conditions, abnormalities, labour contents and time taken to execute the job should be entered fully to allow more detailed analysis at a later stage. (5)

4.0 Predictive maintenance based on diagnostic techniques

Many of the time consuming routines such as open up and inspection requirements of planned maintenance programs can be eliminated through the use of diagnostic techniques. The concept of such a procedure is to monitor condition of machinery as it is operating.

Through the gathering of certain dues by the use of these methods, the shipboard engineer can determine the health of a machine. The purpose of using this technique is not to bypass the maintenance needed, but to avoid routine interference with machinery that is running well. Further, this technique can establish trends in the operating characteristics of machinery which will indicate when deterioration is developing so that timely repair action may be planned and taken. (4)

4.1 Diagnostic techniques employed in predictive maintenance (condition monitoring)

Condition monitoring can be stated to be an assessment on a continous or periodical basis of the mechanical condition of machinery equipment and systems from the observation and/or measurements of selected parameters

4.1.1 Lubrication oil analysis

It is usual for the original charge of lubricating oil to remain for some years without change in most of the systems that require a large quantity of oil to be used, due to the considerable cost of oil.

If the oil is heavily contaminated or has otherwise deteriorated to the extent where engine failure occurs, the cost will be very large. Hence, an oil analysis service to assure that the oil is in good condition or, alternatively, to advise as an effective diagnostic tool for remedial action in good time, makes a positive contribution to the efficient operation of the vessel.

4.1.1.1 Routine oil testing requirements

A. Sampling generally every three or four months gives satisfactory assurances of machinery condition to be monitored, except for a new or reconditioned piece of machinery or temporarily contaminated lubricant when there would be logical reasons for an additional sample.

B. Sampling requirements

- The sample should be representative of the total oil in the system, regardless of the sample volume.
- The sample is fully identified and correctly dispatched.
- The sample should be drawn from a connection that comes directly out of the main oil supply to the engines.
- Total quantity of oil in circulation is approximately the same at each sampling.
- The sample should be taken only when the oil is up to its operation temperature with the engine running.

4.1.1.2 The significance and interpretation of oil analysis results

The significance of the results of analytical tests on a sample of oil can only be assessed if the results of the various tests are considered together and in relation to the oil's past analytical history and to the conditions of operation. It is rarely possible to stipulate for any particular test, a limiting value at which the oil should be condemned or passed as fit for further service. However, the following paragraphs contain notes on the significance of the various tests conducted under the Shell Rapid Lubricants Analysis (Shell RLA) method.

It is necessary to follow the manufacturer's advice in setting lubricant results limits.
Under RLA results, the limits are given in three categories, namely normal-attention-action.
When the results fall within the attention or action limits, it often requires the experience and judgement of a technical expert. The decision to act on these results is that of the ship's chief engineer, supported by the superintendent engineer.

A. Viscosity is generally the most important single property of a machinery lubricant, since it determines not only friction but also the load-carrying ability of bearing contacts.

The viscosity of an oil system may change in service due to oil deterioration and/or contamination. Sooty insolubles and oxidation will cause an increase in viscosity, while fuel and water contamination may cause either an increase or a decrease in viscosity. Accordingly a change in viscosity should be considered in relation to other test data, such as TAN for oil oxidation, index of contamination, water content, and closed flash point for dilution by light fuel and/or cleaning fluids. If, however, these test data reveal nothing unusual, change in viscosity may simply indicate an admixture of lubricating oils in the system.

Decreasing viscosity is obviously of greater importance than increasing viscosity, in fact a level may be reached which is insufficient to maintain full film lubrication, while an increase of viscosity may be tolerated without causing difficulty due to increased fluid friction. (8)

B. Closed flash point: A drop in a closed flash point indicates contamination by fuel. It should be noted that, if the contamination occurs with marine diesel oil or gasoil, the fall in flash point will be accompanied by a fall in viscosity. Contamination by marine fuel oil will often cause a fall in flash point, but the viscosity will rarely show a reduction. In neither case can any reliance be placed on the fall in flash point being used in a quantitative manner, to estimate the amount of fuel contamination, since the flash point of the fuel will normally not be known. (8)

C. Water content: In marine systems, traces of water in the lubricating oil are inevitable and may come from such sources as salt water from leaking oil coolers, fresh water from cylinder and piston cooling water leaking in diesel engines and from glands in all types of machinery, from atmospheric conditions.

The presence of water will, of course, affect the viscosity of an oil and may give rise to emulsion formation. Water can also lead to bearing failures, particularly in medium to high speed diesel engines. Accordingly the water content must be maintained below an acceptable maximum, usually by centrifuging for marine system oils.
If there is significant water content in an oil system, it is advisable to check the adequacy and effectiveness of the centrifuging operation. The cause of any undue water contamination must be traced and eliminated.

D. Total Base Number (TBN) is primarily a measure of the ability of an oil to neutralize strong acids caused by the products of combustion condensing on the cylinder walls, and hence control wear with heavy duty engine oils. It is also a guide to effective additive content, and for oils having alkaline multi-functional additives, gives some indication of the condition of the oil in respect of the detergent, antioxidant and anticorrosive antiwear properties of the oil.

During service in a trunk piston engine the TBN of the appropriate crank oil will fall from its initial value to an equilibrium level at which it will remain indefinitely unless operating conditions change. The factors which influence the equilibrium level are the fuel sulphur content and the oil consumption. A higher sulphur fuel will cause the TBN to fall and vice versa. Conversely, an increase in oil consumption will raise the TBN while a reduction in oil consumption will cause a fall in the equilibrium. In addition, if the oil used for topping up the engine is changed for an oil of higher initial TBN, the equilibrium level will rise.

The effect of changing these three factors is predictable.

Assuming the operating conditions and oil history for an individual engine are known, a simple calculation will give the initial TBN of a different oil required to compensate for change in fuel sulphur or oil consumption.

Many engine manufacturers specify the minimum equilibrium TBN of the used lubricant and their requirements must be observed. With additive oils in cross head engine systems, the equilibrium TBN can fall to quite low levels without posing any significant dangers, since at least some alkalinity can be regarded as being superior to a straight mineral oil having none. Nevertheless, the level of protection afforded by high quality grades is reduced and it is recommended to look for and rectify the cause of undue of TBN depletion. Possible depletion causes are continuous washing, whether deliberate at the centrifuge or inadvertently by contamination, undue contamination by acidic cylinder drainings passing piston rings and piston rod glands. (8)

E. Total Acid Number (TAN) is a measure of the total acids present in the oil.
In hydraulic oil these will normally derive only from oil oxidation (weak acids).
TAN is not normally determined on heavy duty engine oils, however, where straight mineral oil is used in a diesel engine system, the TAN should not be allowed to exceed the attention limit, if there is any indication that the rate of increase is rapid.
If the TAN is only rising slowly at this stage, the oil can normally be allowed to remain in service until the action limit is reached. TAN must, however, be considered in relation to Strong Acid Numbers since the oil should be changed if any strong acid is found to be present. When TAN rises prematurely, it should be urged to investigate and eliminate the cause, e.g. leaking piston rings or glands, as a matter of urgency.

With hydraulic oils in good condition, the TAN should not exceed the attention limit. However, when such an oil is approaching the end of its useful life, TAN will rise rapidly, and again it is the rate of increase that dictates the need for an oil change. If the TAN reaches the action limit, it should certainly be advised to have the oil changed.

The weak acids formed when oil is oxidised do not attack ferrous metals or white metal, but can cause corrosion of copper/lead bearings.
"Water washing" helps to reduce the TAN of straight mineral oil. (8)

F. Strong Acid Number (SAN) in additive engine oils can occur only if the TBN is zero and in such cases (which are very rare), the oil should be changed and every effort should be made to eliminate the source of strong acid.
When straight mineral oils or rust/oxidation inhibited oil are used as system oils, it is possible for strong acids to find a way into the system by leakage from cylinder oil; and in such cases, water washing with the centrifuge is effective in removing such acids. The source of strong acid should be traced and eliminated. (8)

G. Index of Contamination (IC) from "the blotter spot" adopted by Shell RLA the quantity of sooty combustion products in the oil is computed radically, and these are expressed as percent weight of the oil. The values are numerically equal to those obtained by the traditional test method IP 316 in which the results are reported as percent weight of heptane insolubles. The presence of such contamination will lead to a rise in the viscosity of a system oil and may result in the formation of sludge.
Good combustion combined with suitable purification of the oil normally minimises the accumulation of these contaminations. High IC values in crosshead system oils generally indicate

undue contamination by cylinder drainings that have found their way into the system by way of deterioration stuffing box sealing rings .

IC values in trunk piston crank case oils which are abnormally high for the engine type are likely to be due to sooty combustion and/or faulty centrifuging which should be corrected accordingly. (8)

H. Metaling content is determined spectroscopically, indicates the level of trace elements. A change in trace element level in the oil, or drastic buildup of certain elements can indicate a need for corrective maintenance.

The existence of metals in lubricating oils according to their likely origin can be considered in five groups;
- lub.oil additives - calcium, barium, phosphorus, zinc;
- cylinder liner and piston ring wear - iron, chronium, molybden aluminium;
- bearing wear - tin, lead, copper, aluminium; and
- fuel contamination - aluminium, vanadium, silicon, sodium. (8,4)

4.1.2 Shock Pulse Mesurement (SPM) is a type of vibration - measuring technique useful for indicating deterioration of some types of machine elements.

Shock pulses are short duration pressure pulses which are generated by mechanical impacts. Mechanical impacts occur in rolling element bearings as a result of irregularities in race-ways and rolling element surfaces. The magnitude of the shocks depends on impact velocity.

The SPM, used to detect and analyze shock pulses, uses two levels of readings to establish the operating condition of a bearing: DBC (Decibel Carpt value) and DBM (Decibel Maximum value). Basic SPM equipment consists of a special meter and a transducer to pick up shock pulses on a bearing.

Surface roughness (small irregularities) of a normal, properly lubricated bearing will produce a rapid sequence of minor shock pulses, which together constitute the shock carpet of the bearing. The magnitude of the shock carpet, which gererally is low, is expressed by DBC.

Faulty alignment and installation or insufficient lubrication will reduce the thickness of the oil film in all or parts of a bearing. This will cause the DBC to rise above normal limits.

Bearing damage, i.e. relatively large irregularities in roller and/or race surfaces, will cause single shock pulses of high magnitudes at random intervals. The highest shock pulse value measured on a bearing is the DBM.

By measuring DBC and DBM the operating condition of a bearing can be established. Variations from normal limits will signal incipient problems and indicate their nature. Thus they can form another basis for an effective predictive maintenance system. (4)

4.1.2.1 Allowable levels for shock pulse measurements

Shock pulse measurements are treated somewhat differently from other types of vibration measurements. Since shock pulse signals are generally at very high frequencies (around 32 KHz), they must be measured close to their source and are not normally susceptible to contamination by extraneous signals.

The term "shock pulse meter" refers to a proprietary system offered by a single manufacturer. In this system, a "shock value" of 1.0 is assigned to particular level of signal intensity. The "normal" shock value for a given size of bearing is found from the expression:

$$SV = (KXRPM)/400$$

The factor K is a bearing constant which can be found from the bearing manufacturer's published data or from expression:

$$K = (d+(D-d)x0.25)/(\sqrt{(D-d)x0.25})$$

where d = bearing inside diameter.

D = bearing outside diameter.

The resulting shock value is then converted to decibels by the relation; $SPdB = 20 \operatorname{Log}_{10} (SV)$

The maximum permissible shock value is 10 times "normal" shock value. Converting to decibels, this is 20 dB above the normal reading. When the shock pulse reading reaches such a value, maintenance action is indicated. A sharp upward trend in SPdP may lead to a decision to take maintenance action before the maximum permissible value is reached. (4)

4.1.3 Borescope inspection

A borescope is an optical device with a small light at the end which enables the user to observe conditions in small, otherwise inaccessible regions. Using fiber optics, the borescope comes more into intricate passages to observe, for example, the buildup of deposits on gas turbine blades, the erosion of low pressure steam turbine blades by condensation, or the deterioration of valves in a diesel engine. It can be fitted with magnifiers to search for stress cracks and with long extensions to reach regions remote from access holes. Thus, this is useful in checking the condition of machine

The borescope is limited to searching for possible failures or the cause of reduced operating efficiency when a machine is shut down. It cannot be used to warn of incipient failure of an operating machine. (4)

4.1.4 Thermography

Thermography is a process for determining variations in the surface temperature of structure and equipment. With temperatures above 260 C the relative temperature on a surface may be indicated by taking a picture on infrared film, at temperatures below 260 C the wave length of emitted heat is too low for this method to be sensitive.

Thermography is valuable for showing poor electrical contacts, overloaded wiring, overheated bearings, steam leaks, deteriorating thermal insulation, fire brick deterioration, and similar problems which produce local heating. (4)

4.1.5. Vibration monitoring for rotating machines

Every rotating machine has a characteristic vibration pattern known as its vibration signature. The type and condition of bearing, the balance of rotors, the clearances in bearings subjected to alternating loadings etc. All are factors which establish the baseline signature of a machine. As these factors change with deterioration or failure of machine elements, the vibration signature of the machine will change.

Vibration signatures are usually measured in regions that are accessible and where deterioration is most apt to occur, such as at bearings. When properly interpreted, they can give an indication of deterioration and incipient failure.

4.1.5.1 Capabilities of vibration measuring instruments

Every vibration measurement instrument is composed of two distinct parts, one is a transducer and the other is a signal processor. The purpose of the transducer is to convert the mechanical motion to be measured into a signal which can be processed by the signal processing equipment. Almost inevitably the signal produced by the transducer is electrical. This is because modern signal processing equipment works on electrical signals.

The engineers are usually interested in some particular aspect of the vibratory motion such as root mean secure (rms.) value of displacement, the amplitude of various harmonic frequencies contained in the signal, etc. The purpose of the signal processor is to provide a description of the desired characteristics of the vibratory motion on a form of (output) which can be used for engineering purposes.

1. Type of transducers

There are two different classes of transducers that should be distinguished.

The first class covers those which measure vibratory motion relative to inertial space, that is a fixed, nonaccelerating coordinate system. These include all accelerometers and some velocity measurement transducers. The transducer is designed to measure motion in one direction only. Any response of the transducer perpendicular to vibration motion is undesirable.

The second class covers transducers which measure the vibration motion of one body relative to another, displacement transducers. Probably the most important vibration transducer of this class is the proximity detector with small displacement capability and high resolution. Either capacitive or inductive phenomenon are used as the basis for such transducers. However, inductive devices are most widely used to monitor the relative motion of rotating shafts with respect to their bearing housings.

2. Signal processing to obtain absolute displacement measures.

The inertia-type transducers do not measure absolute displacement of the vibrating body but rather its velocity or acceleration. On the other hand, proximity transducer measures the relative displacement of the vibrating body. If it is desired to determine the absolute displacement, with a inertia-type transducer, then it is possible to integrate the electrical output of the transducer in the signal processor. On the other hand, the output signal of an instrument which measures displacement cannot easily be converted to velocity or acceleration.

3. Signal processing to restrict bandwidth of transducer output

In vibration measurement systems it is necessary to restrict the measurement bandwidth. This may be accomplished through choice of transducer, or it may be done in the signal processor.

Neither the inertia-type accelorometer nor velocity transducers will respond at zero frequency cutoff. However, it is important that the low frequency cutoff is not so high as to interfere with faithful transmission of those low frequency components of the vibration signal which are of interest.

A transducer signal tends to have high frequency noise. If the signal is to be integrated, the integrator automatically eliminates high frequency noise. If no integration is used, then a separate operational amplifier stage with a high frequency cutoff may be desirable to limit the bandwidth of the transmitted signal.

Filters not only attenuate signal frequency components outside the passband, but they also may cause considerable phase shift of desired frequency components near the edges of the passband. Therefore, the passband of any proposed filter circuit must be considerably wider than the bandwidth which encompasses the signal to be measured, otherwise, phase distortion of the desired signal will result.

4. Broadband measurements

The most elementary form of signal processing is the so called broadband measurement. In this case, the transducer signal is integrated if required and bandlimited. The resulting signal may be rectified, amplified, and subsequently connected to a meter. Such meters produce a pointer deflection which is proportional to the time average of the input voltage.

Depending upon the instrument, a broad band vibration measurement is either the average of the rectified incoming signal or the (rms) value. In the case of an average reading meter, one must discover whether the scale reading is the true average or is calibrated to give the (rms) value when a pure sine wave is applied.

5. Decomposition of vibration signal into harmonic components

Any period wave form can be represented by means of a "Fourier series" which is a sum of sine waves with frequencies which are multiples of the fundamental frequency. Thus, if the wave repeats itself every T seconds, the fundamental frequency is 1/T hertz and the Nth harmonic is N/T.

A harmonic wave analyser is essentially a tuned circuit which transmits only the frequency to which it is tuned. The tuned frequency can be varied. By varying the tuned frequency over the bands which contain the harmonics of the vibration signal, it is possible to determine the amplitude of each of the harmonic components. Since the harmonics are by definition sine waves, the output device may read the (rms) value of the harmonic voltage value. The operator of the analyzer must determine what it measures in order to convert the signal to vibration acceleration, velocity or displacement as desired.

Bandwidth is important because it is a measure of the ability of an analyzer to sort out the various harmonics.

If bandwidth is too broad, response from two adjacent harmonics may each be transmitted, and it will be impossible to distinguish between them. (4)

4.1.5.2 Sources of vibration signals

From a condition monitoring point of view vibration signals in machines may be divided into two broad classes;
internally generated signals, which may provide useful indications of machine condition: and external signals, usually transmitted to the machine through ship structures.
External signals are usually considered to be undesirable "background noise" since they may mask useful internal signals.

1. Background signals

A. Propeller and shafting:

The primary source of background noise signals in a ship propulsion and auxiliary machinery plant is the ship propeller and shafting system. Because the propeller is operating in a non-homogeneous wake, nearly every ship displays a strong vibratory excitation at propeller blade rate frequency. This is defined as the shaft rotational frequency times the number of propeller blades. Blade frequency vibration is often measurable throughout the ship and may be the predominant signal in measurements taken on the ship machinery components. Occasionally higher harmonics of the blade frequency are also significant and may tend to mask a particular machine's vibratory signature.

In addition, low frequency background vibratory excitations may also be produced in the propeller and shafting system at a shaft rate frequency. These are caused by mass or pitch unbalance in the propeller or shafting system. Usually the magnitudes of such signals are significantly less than those at blade rate frequency.

B. Reciprocating prime movers

Diesel engines also may act as sources of background noise signals. While auxiliary engines are often isolated from the hull structure by resilient mounts, the need to maintain precise shaft alignment has so far dictated the propulsion diesel engines be hard-mounted. As a result, engine- excited vibrations are transmitted to the hull structure which in turn may carry them to virtually any part of the ship.

The vibrations of diesel engines are caused by the inherent design characteristics of reciprocating machines. While careful choice of firing order and proper arrangement of crank shaft counter weights can minimize such vibrations, it is not generally possible to eliminate them completely. The exciting forces occur primarily at one and two times the crank shaft RPM. They may consist of vertical and horizontal forces, moments about the pitch and yaw access, or any combination of the four.

Since the torque generated by a diesel engine is not uniform, the engine will also produce torque impulses. The reaction of the engine block to the impulses frequently is a cause of undesirable vibration of the ship's structure. For example, while passing through a "barred speed range" reaction torques in a large, direct dirive diesel engine produce vibrations which often can be induced by pressure fluctuations on the hull caused by propeller torsional vibration.

The predominant frequency of torque impulses will be the cylinder firing frequency which equals the number of cylinder times the shaft RPM in a two stroke engine or one half this frequency in four-stroke engines. Multiples of this predominant-frequency may also be strong. Weaker impulses may be detected at other integral multiples of the shaft RPM in two-stroke engines and at other integral multiples of half the shaft RPM in four stroke engines.

C. Other sources

In addition to the engine and propeller, virtually any nearby machine can act as a source of background noise for the machine or component being analyzed due to the abundance of paths for structure borne transmission of vibration.

2. Internally generated signals

A. Rotating machines

Most usable vibration signals from rotating machinery are generated at frequencies related to the speed of rotation of the machine. The fundamental rotation frequences is often the signal of greatest interest. Its magnitude is indicative of the degree of unbalance present. Changes in the amplitude of the fundamental frequency signals may also be generated by machine looseness, misalignment, casing distortion/cavitation, or an open iron in a motor rotor.

The machine conditions noted above can also produce significant vibratory signals at two and three times the fundamental rotational frequency sometimes strong axial as well as lateral components.

Rotating machinery with blades or vane elements (pumps, fans, compressors, turbine, etc.) may generate vibration signals of interest at frequencies equal to the number of blades/vanes times the running speed frequency. The amplitude and utility of these signals are strongly influenced by blade/vane versus rotor/shaft versus hausing/cover mass relationships. Thus, fans and pumps with relatively massive blade/vane elements with respect to their shaft/rotor masses may yield much useful data. On the other hand, turbines and compressors with blades of relatively small mass with respect to their rotor/shaft masses yield vibration signals at the casing which are more difficult to sense and measure, and consequently are less useful for condition monitoring purposes.

Oil film instability in journal bearings may produce measurable vibration signals at a frequency equal to 40-50 percent of the fundamental rotational frequency.

A summary of the most common type of vibration signals generated by rotating machines, together with their most frequent causes, is given in Figure (1)

B. Ball and roller bearing internally vibration generated signals

Anti-friction ball and roller bearings generate vibration signals at a number of frequencies related to their running speed and geometry. They also generate harmonics of those frequencies as well as broad-band noise which can be related to the condition of the rolling surfaces. Balls rolling over rough surfaces generate impulse type noise which may extend well into the ultrasonic frequencies. These can be detected and analyzed by instruments of the shock pulse type.

C. Reciprocating machines

In reciprocating machines, vibration signals generated by crank shaft related faults are generally not useful to a vibration analyst because they cannot be separated from inherent vibrations of the rotating and reciprocating masses. There are, however, many other events occurring in and around the cylinders which generate intermittent vibration signals. These include valve action, injector operation, etc.

D. Other effects

There are a number of other machine faults which do not have vibration signals associated with them, for example uniform erosion of (or deposits on) the blades of a turbine rotor may not produce a measurable imbalance. (4)

4.1.5.3 Separating signals from noise (signal identification)

It is necessary for any shipboard predictive maintenance programme using vibration monitoring to have the ability to identify and utilize the vibration signals generated within a machine without being misled by the background noise discussed in (background signal section).

1. Susceptibility to signal contamination

Depending on the characteristics of machine moving parts, casing, and foundation as well as its location in the ship, a particular machine may be more or less susceptible to contamination of its vibration signals by externally generated background noise. In general, the following types of machines are relatively free of signal contamination;

- machines on soft spring mountings;

The most serious problems of signal contamination are generally associated with;

- small, light-weight machines;
- machines hard-mounted to steel foundations; and
- machines located in areas of high structural vibration, such as steering gear flats, aft engine rooms, etc.

2. Signal contamination surveys

The presence or absence of signal contamination will influence the type of instrument selected for monitoring, the conditions under which measurements should be taken, and the criteria to be used in determining the need for maintenance action. Therefore, it is important to conduct an initial vibration survey, using a sophisticated type of spectrum anlyzer, to establish the degree of signal contamination present at each machine before developing a detailed monitoring plan for the engineering plant. This initial investigation can be the baseline survey which will be described in a latter section. To conduct the investigation effectively the characteristic range of frequencies of each machine (or other source of vibration) should be known.

As discussed in section (sources of vibration signals), most rotating machine vibration will occur at orders, integral multiples, of the machine RPM. On the other hand, most background noise will occur at orders, multiples or half multiples, of main engine or propeller RPM. Occasionally, signals will be detected at other frequencies as well. These can usually be traced to nearby machines, particularly when several machines are mounted on a common structural platform or foundation.

Identification of individual peaks can be confirmed by changing the rotating speed of each suspected signal source. If the peaks are correctly identified, their frequencies will shift in proportion to the speed change. This shift is easiest to visualize using a real time analyzer with an oscilloscope display but can also be detected with less sophisticated devices.

A useful technique for understanding the effect of the foundation design on the vibration behaviour of shipboard machinery is a "coast-down" measurement. This consists of watching or plotting the amplitude of vibration as a function of both time and machine speed after shutting off power to the prime mover. If the vibration amplitude (usually broad band) increases as machine speed decreases, a structural resonance is indicated. This condition may not need to be corrected, but it should be noted as a possible cause of unexpected high vibration readings.
A similar technique can be used to determine whether a resonance exists with an external signal source.

3. Selecting a monitoring technique

The relationship of background noise to machine signal will have a significant influence on selection of instrumentation and monitoring techniques. If there is some doubt about the comparative strengths of the signal and the noise, a simple technique can establish which is dominant. Broad band (filter out) readings of both displacement (peak to peak) and velocity (single amplitude) are taken on the machine in question. Then on a vibration severity chart such as Figure (2) the frequency at which the observed displacement and velocity coincide is determined. If that frequency is characteristic of the machine the signal is dominant. If it is not, then background noise is dominant whether from an identifiable signal source or a medley of sources.

If the machine signal is dominant, a relatively simple broad-band instrument can be used for monitoring with no special precautions taken to minimize the effect of background noise.

If noise is dominant, then either more sophisticated instrumentation designed to filter out background must be selected or special operating precautions to minimize the background noise must be taken. Such precautions could include shutting down those machines which are prime contributors to the unwanted background noise if such can be accomplished without affecting the normal operation of the machine under study. In such cases, records should be kept of the machines shut down so that future vibration surveys can be made under the same operating conditions. (4)

4.1.5.4 Vibration survey procedure and allowable vibration levels. Vibration analysis as discussed in previous sections can supply a very effective tool, along with records of other operating characteristics, for answering the questions which are central to a successful predictive maintenance programme;

- Is this machine healthy?
  If not
- Should the machine be scheduled for repair?
  and
- Can the machine continue to run until a convenient time for repair?

The following sections will provide a reliable answer to these questions.

1. Baseline surveys-general

Vibration based maintenance decisions should be based on two criteria:

- the present vibration level, and
- the trend of vibration levels over several intervals of time from an established baseline representative of a "healthy" machine.

The data for vibration signature baselines should be obtained during dock and sea trial of new ships, or during post overhaul trials of old ships for which a vibration based maintenance system is being introduced, in order to assure that each machine element being surveyed is in good operating (e.g. healthy) condition.

The baseline survey should be carried out by properly trained personnel using spectrum analyzers. It should provide a permanent record of the vibration signature at each measuring point of each machine to be monitored. It not only will indicate the signatures of healthy machines but, through careful analysis of the results will:

A. assure that monitored machines have no faults requiring immediate attention; and

B. determine levels of signal contamination at each measuring point, as described in section (separating signals from noise) to guide the selection of instrumentation and monitoring techniques for future periodic surveys.

2. Baseline surveys criteria and their application

While the primary purpose of the baseline survey is to gather data for future use, it is probable, particularly in older

ships, that one or more machines will be found to have faults which should be corrected immediately. It is, therefore, necessary to have some criteria for establishing the health of a machine solely on the basis of baseline data.
This often requires a considerable amount of judgement on the part of the analyst since satisfactory vibration characteristic criteria for one time measurement are somewhat loosely defined.

A widely used set of criteria which uses narrow band velocity measurements taken on the machine casing, usually in the way of the bearings, are based on the work presented in Figure (2). Note that the vibration severity is expressed in terms of the peak velocity. While many commercially available instuments are calibrated to read directly in terms of peak velocity, it must be remembered that the instument is actually sensing the average (or in some cases the rms) velocity. Although this distinction is often not of practical importance to the use of a particular instrument, it may result in differences between measured levels obtained with different instruments.

Because broad band meters are calibrated in different ways, it is often difficult to correlate broad-band readings with the narrow band readings. Therefore, it is wise also to take broad band readings with the meter or meters which will be carried aboard ship as a part of the baseline survey, if shock pulse measurements are to be used for periodic checks. Such measurements should also be taken during the baseline survey.

An alternative set of criteria, based on broad band (rms) velocity readings, is given in ISO standard 2372. These criteria, shown in Figure (3) have the advantage of offering appropriate vibration levels for particular classes of machinery and type of foundations.

When applying ISO 2372 broad band vibration level higher than the midpoint of severity rang "C" together with a signature analysis giving clear indications of a fault, it would probably lead to a recommendation to repair before establishing the baseline signature for a preventive maintenance programme. The above suggested values may need to be adjusted in case of foundation resonance or heavy signal contamination. The recommendations of individual machinery manufacturers, if any, should take precedence over other criteria described herein.

3. Periodic vibration checks

Having established a baseline and confirmed that all machines to be monitored are initially healthy, a program of periodic checks may begin, on a monthly, bimonthly or quarterly basis.

The objective of these checks is either to confirm that the machine remains healthy or to detect the presence of a fault at an early stage. Periodic vibration checks are usually made with a broad band vibration meter unless the results of the signals to noise ratio study dictate otherwise. Vibration velocity is usually the measured variable.

It must be remembered that some machine faults do not produce significant changes in broad band vibration levels. While some changes in broad band vibration levels are not produced by faults within the machine for these reasons it is recommended that a complete signature analysis be performed once a year to supplement and to help interpret the results of periodic broad band checks. Also for the above reasons, an increase in the broad band vibration signal of an otherwise healthy machine is not of itself considered to be an indication that major repair is required. If minor corrective action such as cleaning, tightening of belts and foundation bolts, etc. does not result in a reduction in the broad band vibration level, then a more searching diagnosis is appropriate to identify the cause.

4. Vibration criteria for periodic check

The broad band vibration level at which a machine should be designated for minor corrective action and/or further diagnosis may be determined in any one of the following ways.

A. When the broad band reading reaches the acceptable limit established at the time of the baseline survey;
B. When the broad band reading reaches a predetermined multiple of the baseline broad band vibration level, as determined frame table. (1)

In general the lesser of the above values should be used, and should be clearly indicated for each machine in the record keeping system employed for this purpose. In addition, the broad band reading may be plotted over a period of time. If this is done, a need for corrective action and/or further diagnosis may also be indicated when an unusual increase in the vibration level is noted.

5. Fault diganosis and repair decisions

In this discussion, it will be assumed that a serious fault is suspected and that minor maintenance has not succeeded in reducing the broad band vibration level. Further diagnosis and possibility extensive repairs are now in order.

A complete vibration based fault diagnosis requires, as a minimum, a tunable filter vibration meter or spectrum analyzer, although a broad band meter may be able to identify the predominant frequency of vibration using the technique described in (selecting a monitoring technique section). If the necessary equipment is not immediately available, the chief engineer must decide whether to shut down the machine pending further diagnosis or to continue running it. This decision should be based on all available information, including that provided by his eyes, ears, nose and instincts, as well as performance data, lubrication oil analysis reports and the rate of increase of the vibration level.

A trend analysis of the broad band vibration reading, although useful in detecting the presence of a fault, has not been found to be a reliable indicator of the growth rates of some types of faults. A slow rate of increase in broad band vibration levels should not, therefore, be taken as a clear indication that a suspect machine may be allowed to continue running unless supporting information from other sources also is favourable.

On the other hand, a sharp upward trend in broad band vibration reading is a reliable indication that the machine should be shut down, especially if the upward trend suddenly becomes sharper or the vibration level already exceeds the allowable limit.

In order to minimize the chance of sudden failure, the interval between vibration readings of the suspect machine should be shortened as much as feasible until a complete diagnosis and/or repair is made.

Once diagnostic equipment is set up, every effort should be made to reproduce the conditions of the baseline survey (ship speed, draft, condition of adjacent machines, etc.). A comparison may then be made between the current amplitudes of the individual frequency peaks and those reported in the baseline survey.

An increase in one or more single frequency peak amplitude may be taken as a clear indication of a developing fault, which may be identified from the list of characteristics given in (source of vibration signals section). An excessive increase in one or more signal peaks is an indication that repairs should be made, regardless of the accompanying broad band vibration reading.

6. Trend analysis of developing faults

If immediate repair is not indicated or if carrying out indicated repair is impossible or undesirable at the time of diagnosis, a trend analysis of single frequency peak amplitudes can be used to give a reasonably reliable estimate of the rate of deterioration of the faults to ensure shutdown and repair before catastrophic failure. Trend charting can also be used to monitor the develpment of less serious faults in order to detect any sudden increase in the rate of deterioration. A rapidly deteriorating fault may need to be corrected before the vibration levels reach allowable limits in order to avoid any untimely failure. To be useful in detecting trend increases before a developing fault has led to machine failure, it is obvious that intervals between signature readings must be short. Further, a tunable filter vibration meter or spectrum analyzer rather than a broad-band meter should be used to make the analysis.

7. Confirmation of repair work

Whenever any machine covered by the predictive maintenance programme is repaired as a result of the baseline survey finding, a new signature analysis of that machine should be performed in order that future maintenance decisions can be based on up-to-date, representative, healthy machine data. The signature analysis will also help to confirm the adequacy and effectiveness of the repair work.

Machinery found inoperable at the time of a baseline survey should be subjected to a signature analysis at the earliest opportunity. (4)

Type of Fault	Frequency/Order	Direction	Comments
Unbalance	1 x rpm	Radial	Amplitude Usually Increases With rpm
Misalignment Bent Shaft	Usually 1 x rpm 2 x rpm or 3 & 4	Radial and Axial	May Aggravate Unbalance
Ball/Roller Bearing Noise	See Sect. 1.3.2.2 For Frequencies	Radial and Axial	Levels Vary With Time
Loose Journal Bearings	1/3 or 1/2 x rpm	Mostly Radial	Looseness May Be Speed & Temperature Dependent
Oil Whirl	.42 to .46 x rpm	Mostly Radial	Usually Found in High Speed Turbo Machinery
Hysteresis Whirl	Shaft Critical Frequency	Mostly Radial	Initiated When Passing Through Shaft Critical. Check For Rotor Looseness
Gear Tooth Defects	No. Teeth x rpm and Harmonics	Radial and Axial	Sidebands Around Tooth Freq. May Indicate Shaft Runout (1 x rpm Sideband Spacing)
Loose Mounts or Joints	2 x rpm and .5, 1.5, 2.5 x rpm		
Belt Drive Problems	1 Thru 4 x Belt Rotation Freq.	Radial	
Unbalanced Couples	1 x rpm and/or Harmonics	Mostly Radial	
Reciprocating Mass	1 x rpm and/or Harmonics	Mostly Radial	
Blade Wake Noise	# Vanes or Blades x # Stators x rpm	Radial and Axial	Levels Vary With Turbulence
Electrical Vibrations	2 x Power Line Frequency	Radial and Axial	Should Disappear Immediately When Power Is Turned Off

References: Bruel & Kjaer Instrument Co., "Vibration Analysis of Machinery 1", 2nd ed. B&K, Denmark, #017-82.

Collacott, R. A., "Mechanical Fault Diagnosis & Condition Monitoring", Halstead Press, New York, 1977, ISBN 0-470-99095-3.

Figure 1 Vibration Symptom Chart

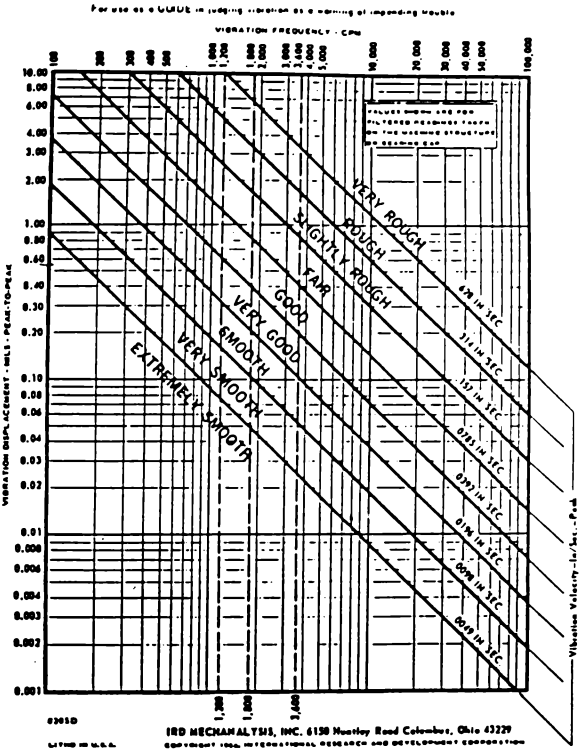


Figure 2 General Machinery Vibration Severity Chart

VIBRATION SEVERITY RANGE LIMITS (RMS VELOCITY)		VIBRATION SEVERITY RANGES FOR MACHINES BELONGING TO:			
MM/SEC	IN/SEC	CLASS I	CLASS II	CLASS III	CLASS IV
0.28	0.011				
0.45	0.018	A			
0.71	0.028		A		
1.12	0.044	B		A	
1.8	0.071		B		A
2.8	0.110	C		B	
4.5	0.177		C		B
7.1	0.280	D		C	
11.2	0.441		D		C
18	0.709			D	
28	1.10				D
45	1.77				
71	2.80				

SUGGESTED CLASSIFICATION:

CLASS I - SMALL (UP TO 15 KW) MACHINES AND SUBASSEMBLIES OF LARGER MACHINES

CLASS II - MEDIUM - SIZE (15 KW TO 75 KW) MACHINES WITHOUT SPECIAL FOUNDATIONS, OR MACHINES UP TO 300 KW RIGIDLY MOUNTED ON SPECIAL FOUNDATIONS

CLASS III- LARGE ROTATING MACHINES RIGIDLY MOUNTED ON FOUNDATIONS WHICH ARE STIFF IN THE DIRECTION OF VIBRATION MEASUREMENT

CLASS IV - LARGE ROTATING MACHINES MOUNTED ON FOUNDATIONS WHICH ARE FLEXIBLE IN THE DIRECTION OF VIBRATION MEASUREMENT

Figure 3 Vibration Severity Ranges (From ISO 2372)

Table 1
TREND ANALYSIS
VIBRATION LEVEL INCREASES

V_0 = Baseline velocity amplitude (in/sec)
V_{max} = Maximum acceptable vibration amplitude (assuming no change in operation)

Baseline amplitude in excess of 0.4 in/sec should be evaluated in terms of the specific machine; i.e., reciprocating engines, compressors, etc.

a. V_0 between .001 and .04 $V_{max} = 6\ V_0$
b. V_0 between .04 and .09 $V_{max} = 3\ V_0$
c. V_0 between .09 and .19 $V_{max} = 2.5V_0$
d. V_0 between .19 and .40 $V_{max} = 1.5V_0$

Example: An original level of $V_0 = 0.10$ in/sec would fall under formula c. "V_0" is between .09 and .19 $V_{max} = 2.5V_0$
A 0.25 in/sec amplitude would signal an unacceptable condition.

5.0 Performance monitoring

5.1 Performance monitoring system for marine diesel engines

Because fuel oil quality, in particular heavy fuel oil, has deteriorated considerably with time, due to the increased use of secondary refining processes, present fuel specification standards and some proposed standards give ample scope for further deterioration. These already lead to a lower ignition quality entering the market, since a lower ignition quality could cause deterioration of a proper engine tuning and/or severe damage on the engine's main bearings unless engines are modified to reduce ignition delay with the use of VIT concept. Such a critical process demands more reliable and available equipment for proper engine tuning whereas the mechanical indicator in these cases is of no use, due to the fact that:

1. Indicator diagrams taken by mechanical indicators do not define cylinder top dead center, nor do they define combustion timing. Without this information, it is not possible to accurately set the timing of the engine.

2. The diagrams set which are taken by mechanical indicators have a poor accuracy. They have, under the best of circumstances, a 7-10% accuracy.

3. Indicator cards show only one individual cycle result. Since the combustion process varies somewhat with energy cycle, the information obtained may or may not actually be representative of what is generally occurring in the cylinder.

4. Indicator diagrams cannot be obtained for medium speed engines above 500 RPM with the use of mechanical indicator.

With the introduction of devices that monitor engine combustion and fuel system condition (mean indicated pressure (MIP) calculators), the engineer can be more acutely aware of how his engine is performing. These devices are a great improvement on mechanical indicators. (10)

5.1.1 A MIP calculator is a device operated by signals from transducers which are fitted to the appropriate parts of the engine. The signals are proportional to:
scavenge pressure, crank angle, fuel oil pressure before the injector, cylinder pressure.

MIP is derived by integration over the compression and expansion strokes, over eight cycles. It is then displayed digitally, together with engine revolutions; maximimum cylinder pressure; compression pressure; expansion pressure 36 deg. after top dead centre (TDC); scavenge pressure; angle between TDC and maximum pressure; fuel value opening pressure; fuel pump discharge pressure, and crank angle between TDC and fuel value opening angle.

An oscilloscope is provided with the system. It displays curves of cylinder pressure and fuel injection pressure, from which permanent records may be taken by polaroid camera. (10)

5.1.2 Objectives of the performance monitoring system with use of (MIP) calculator

There are several objectives of the performance monitoring sytem, namely:

1. to carry out a critical examination of the combustion process and then, through step by step corrective actions, to tune the engine so that an acceptable balance is obtained;
2. to carry out a critical examination of the engine's fuel system and make any adjustments required to ensure correct operation;
3. to provide long term monitoring of engine performance by plotting relevant performance data on "trend graphs";

4. to record engine conditions, at present running hour intervals, for reference purposes;

5. to establish that the engine is operating within design limits and that the bearing load is safe;

6. to determine specific fuel consumption and thus monitor engine performance against a known standard; and

7. the system should be simple, containing as little operational paper work as possible, and be presented in such a way that it could easily be consulted and, therefore, used to best advantage. (10)

5.1.3 Basis for establishing performance monitoring system

Step.1

To construct a model curve depicting the line of optimal performance for the purpose of validation, for the parameters listed below, specially if there are sister ships fitted with the same diesel engine make and type.

The data of these model curves can be collected from engine makers test bedtrials for the concerned engines, taking into consideration any down rating which may have been applied with fitted engines.

1. absolute compression pressure (PCA) to a base of absolute scavenge pressure (PSCA);

2. maximum cylinder pressure (PMAX) to a base of mean indicated pressure (PMI);3. cylinder exhaust temperature (TEXH) to a base of shaft kilowatts (SKW);

4. main engine revolutions (NME) to a base of mean indicated pressure (PMI);

5. scavenge pressure (PSC) to a base of mean indicated pressure (PMI).

6. pressure drop across waste heat unit (PWHU) to a base of shaft kilowatte (SKW);

7. pressure drop across waste heat unit (ΔPWHU) to a base of shaft kilowatts (SKW);

8. pressure drop across air filters (ΔPAF) to a base of scavenge pressure (PSC);

9. pressure drop across air cooler (ΔPAC) to a base of scavenge pressure (PSC);

10. specific fuel consumption (SFC) to a base of shaft kilowatts (SKW), and

11. turbo charge revolutions (NTB) to a base of pressure at turbo-charge outlet (PTB).

Step.2

This step involves constructing the same parameter curves mentioned in Step 1, where the data for each curve is collected from sea trials for the concerned ship's engine.

For sister ships fitted with diesel propulsion machinery of the same make and type, parameters curves can be constructed on the same paper. These will present an ideal opportunity for comparing engine performance across the same make and type.

It seems logical to assume that, across the same engines make and type, fitted on the same ships, there would be very little difference in the results. If this is not the case and the spread of results between them is quite considerable, this could only be explained by:

- variations in ambient conditions from one shop/sea trial to the next;
- variation in the specific energy of the fuel used on the trials;
- incorrect ignition timing on all,`or some, of the engines; and
- inaccurate measurement of trial data.

Step.3

Correction of those curves drawn up during Step (2) if it is required should be based on the values of the standard condition parameters used by engine makers, which are listed in Table (1).

For example; the methods recommended by (MAN-B&W) engine makers to correct variation for some of those affected parameters mentioned in the second step are provided in engine instruction manuals for the following:

1. parameters affected due to a change of suction air temperature (T air in) and charge air cooling water temperature (T cool in) such as: maximum cylinder pressure; exhaust gas temperature; absolute compression pressure, and absolute scavenge pressure.
2. parameters affected due to a change of lower calorific value of the fuel, such as specific fuel consumption.

Tables (2) and (3) list a selection of outside influences and their approximate effect on engine performance parameters. Whenever it is possible to approximate the relationship between each of the two parameters model curve into a straight line, specially within the most often utilized power range (70-100%), it will be much easier to derive the model curve equation. (10,13)

5.1.4 Data collection, evaluation, identification of correction actions, and presentation.

These are achieved through appropriate construction of the performance monitoring system documents.

The system itself can be contained in two documents, an instruction manual and a data recording file. These documents should show in a simple step by step manner using diagrams and tables, how the MIP calculator is used to collect data from the engine and how the model curves are used to monitor performance. Finally the documents should cover fault finding and logging of trends in engine performance.

The instruction manual can be divided into four main sections:

1. Introduction and engine data

The basic concepts and operation of the performance monitoring system can be applied to any marine diesel engine. It is necessary, however, to design certain parts of the system specifically for a particular make and type. The introduction and engine data section therefore contains information relevant only to the engine on a particular ship. Subsequent sections apply to any diesel installation.

Engine data can be presented in the following format:

- timing and dynamic operating conditions;
- measured parameter deviation limits;
- the model curves and their equations;
- typical traces of fuel pressure and cylinder pressure for an engine at 100%, 80%, and 60% load depicting to scale the shapes to be expected and identifying the salient point as it is indicated in Figures (1&2);
- some background theory on the correct procedure for down rating the engine revolutions and main effective pressure, in which the maximum continuous rating (MCR) value of cylinder maximum pressure may be used;
- a load diagram for the engine, clearly defining the operating zone, and
- sketches that show faulty pressure traces and cylinder pressure traces, typical of various engine defects.

2. Pre-performance check

Checks on performance and optimization are described by a series of flow charts showing "go" and "no go" paths. As a diesel engine will operate most efficiently when the fuel system is in perfect order, the pre-performance check concentrates on this area from storage of fuel to its injection into the cylinder. It commences with some simple, but often forgotten, tasks such as checking fuel tank conditions, surcharge pump operation, filter condition and fuel viscosity.

The MIP calculator is then used to measure fuel pressure distribution at each fuel pump and display a set of traces; if required, a permanent record can be obtained in the form of polaroid photographs. The results are recorded on a "performance monitoring log sheet" (PMLS). The data table from the PMLS for fuel system readings is shown in Figure (3), together with the relevant flow chart lines. Log sheets are "customized" for the type of engine and therefore contain normal values and expected limits. Two references can now be used to commence fault finding.

- Comparison of the values of fuel pressure distribution at individual fuel pumps (obtained from the MIP calculator) with the normal values and the limits shown on the log sheet.
- Comparison of the photographs of the actual fuel traces with the ideal trace.

Tuning of the fuel system to achieve "normal" readings across all cylinders, within the prescribed limits, is assisted by sketches that show faulty fuel traces, typical of various engine defects, compared with ideal traces.

A fault finding matrix Figure (4) is also provided, to assist in identifying worn engine parts or incorrect settings of fuel system components.

It is recommended that a complete performance check described below is carried out before corrective action is taken, because the initial engine condition is not known and there is no basis on which to judge any improvements of the fuel system.

3. Performance check

This concerns the measurement of combustion conditions, engine balance and load. The relevant flow diagram Figure (5) includes the recording section from the PMLS entitled cylinder pressure trace.

The performance check commences by using the MIP calculator to measure cylinder parameters; the oscilloscope displays are photographed, and the data are recorded on the logsheet.

For each parameter, the main engine value is calculated for all cylinders and compared with the individual cylinder value, to establish whether an allowable deviation has been exceeded. If there is an unacceptable deviation, the reason is investigated, in much the same way as pre-performance checking. By the use of a fault finding matrix and comparative sketches of faulty and ideal cylinder traces.

Corrective actions can now be taken to achieve engine balance, but they must be carried out in a logical sequence. Since MIP depends on all the other parameters measured, balance can only be achieved by correcting values in the following order; compression pressure; angle between TDC and maximum cylinder pressure; maximum cylinder pressure; fuel pump index; exhaust gas temperature, and mean indicated pressure.

Therefore, after corrective action has been taken to improve compression pressure another complete set of readings should be obtained before the next adjustments are identified and subsequently carried out. Having dealt with compression pressure, balancing can be progressed by moving to (angle between TDC and maximum cylinder pressure) until, finally, the exhaust temperatures are compared; PMI should now be uniform across the engine. At each stage, the fault finding chart and sample traces should be consulted.

Depending upon the engines condition when the monitoring system is installed, it may take several months to complete the adjustments required to achieve engine balance. In fact, the process is continuous, because moving parts are subject to wear and possible failure.

Engine loading should be checked frequently by reference to the load diagram provided with the system, and the main engine controls adjusted accordingly. However, if engine balance is poor at this stage, care should be taken to ensure that individual cylinders are not overloaded.

4. Optimization of performance

Although perfect engine balance may have been achieved during the pre- performance and performance checks, it is unlikely that the engine will be operating at the optimum specific fuel consumption. For example, the maximum pressures in all cylinders may be low, due to a restriction of the air flow or a retardation of the cam shaft. Optimization commences by calculating for each performance characteristic, a percentage deviation from the relevant model curve.

These calculations are recorded in space provided on PMLS Figure (6) which is also the central recording document for all numerical information obtained during the monitoring process.

Since all model curve equations, with exception of that for specific fuel consumption, are straight lines of the form;

$$y = mx+c \text{ thus,}$$

percentage deviation can be calculated with the use of:

$$\% \text{ Deviation} = \frac{\text{Actual-Model}}{\text{Model}} \times 100$$

Where actual is the value of the measured dependent variable (absolute) during engine evaluation;
Model is the value of the calculated dependent variable (absolute) by substituting with the measured independent variable (absolute) in the concerned model curve equation, and % Deviation is the deviation of the measured parameter actual value from the corresponding model curve value.

Calculation of the specific fuel consumption and any deviation from the model value are of major importance. Figure (7) shows the method, which is described below. Volumetric flow from the fuel meter is converted to mass flow by using the specific gravity of the fuel, corrected for temperature at the fuel meter with use of correction tables. An initial value of SFC is obtained by dividing the mass flow rate by the engine SKW. This initial value is then corrected, if necessary for three significant factors by the use of calibration value , which is listed in Table (3) for the first two factors.

- The difference between the actual scavenge air temperature and the system standard of 45°C.
- The difference between the actual turbo blower air inlet temperature and the system standard 27°C.
- Whereas the third factor is the net specific energy of the fuel,

Correction is based on the following empirical formula:
Net specific energy (MJ/kg)
$= (46.392-8.792 \rho^2+ 3.187\rho)(1-(x+y+s))+9\ 4205S-2.449x$

Where ρ = density at 15 C of the concerned fuel.
X = proportion by mass of water (% divided by 100)
Y = proportion by mass of ash (% divided by 100)
S = proportion by mass of sulphur (% divided by 100)

The use of the above formula is limited to where a complete analysis of fuel is obtainable at the time of use in the engine. Since this information is rarely available, a degree of simplification is essential. This can be achieved by using of graphic forms that study specific energy change with change of density and sulphur content. In most of the cases this is provided in instruction manuals. If this is not the case, B.S. MA 100 or ISO/ D168217 can be consulted for reference.

The fully corrected SFC value is then compared with the model value and the percentage deviation is calculated.

Another useful method of monitoring specific fuel consumption is by calculating the fuel consumption index. Since the quantity of fuel passing to the engine is proportional to the Fuel Pump index (FPI) and the engine speed (NME), then their product, divided by shaft kilowatts (SKW), will bear a direct relationship to the specific fuel consumption, i.e:

Fuel consumption index = (NME x FPI)/SKW.

It should be noted that the index will tend to increase slightly with fuel pump wear, but this is a long term effect. A trend graph of the index is useful, but more important, calculation of the index immediately before and after adjustments to the main engine will clearly show whether the specific fuel consumption has changed.

The optimization process is completed by reference to a matrix Figure (8) showing, for high positive or negative deviations, the faults present in the engine's overall conditions. Deviations are then transferred to the long term trend graphs, which can be designed to cover approximately two years operation of the engine.

Apart from their major function as the basis for optimizing engine performance, the concise nature of the PMLS (containing all numerical data, fuel system settings and recommended maintenance work) and the trend graphs mean that they have additional uses:

- as a permanent on board record showing main engine performance, maintenance history and fuel system settings;
- as an aid to handing over the vessel to relieving engineers;
- as a quick reference for visiting superintendents to gain a rapid assessment of engine performance and trends; and
- as a reference, either complete or in an abridged form, in the head office in case of emergency.

Fig.(9) shows a complete flow chart for the pre-performance check, performance check and optimization of performance.

5. Presentation of results

The final stage in an energy conservation system is the presentation of the results in a clear, concise manner, to both technical and commercial management. For this purpose, graphs can be constructed for each of the model curves relationships to show the comparative position of:

- the performance monitoring system model curve;
- the condition of the engine on the trial trip;
- the condition of the engine at the time when the performance monitoring system was installed; and
- the condition of the engine after the performance monitoring system had been in use for say 2000 hours. (10)

Table (1)

Standard **Parameters**		Sulzer	ISO (30461)	B & W
Total parametric pressure		1.0	1.0	1.013
Suction air temperature		27	27	27
Relative humidity of suction air %		60	60	---
Charge air cooling water temp. %		27	27	27
Scavenge air temperature %		45	45	30
Lower caloritic value of fuel oil	KJ/kg	42.707	42.000	42.920
	Kcal/kg	10.200	10.030	10.250

Table (2)

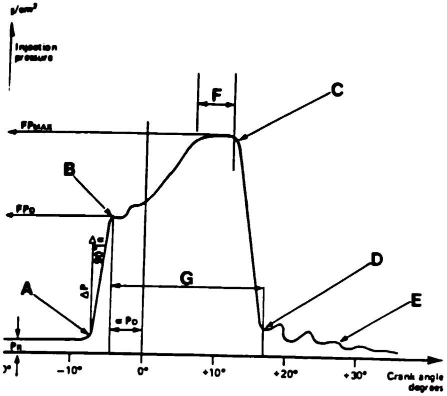
Performance parameter % change due to change of standard condition

Performance parameter	Ambient temperature ± 10°C	Ambient pressure ± 10 mm Hg	Scavenge air temp. ± 10°C
Air mass flow to main engine	± 0,31 %	± 0,18 %	± 0,36 %
Scavenge pressure absolute	∓ 2,03 %	± 0,15 %	± 1,45 %
Exh. temp. after turbin absolute	± 1,91 %	± 0,04 %	± 1,35 %
cylinder max. pressure absolute	∓ 1,37 %	± 0,3 %	± 0,27 %

Table (3)

Specific fuel consumption measurement tolerances

effecting parameters	calibrations of SFC	
	test bed	ship board
. water brake	± 0,25 %	± 2 %
. change air temp. (± 10°C)	± 0,75 %	± 0,75 %
. atmospheric temp. (± 10°C	± 0,50 %	± 0,50 %
. combustion pressure diff. (5 bar)	± 1,0 %	± 1,0 %
. lower calorific value ± 0,5 %	± 0,5 %	∓ 0,5 %
. fuel flow measurement by weight	± 0,1 %	± 0,2 %



A	Pump spill closes	8 deg approx BTDC
B	Fuel valve opens	4 deg approx BTDC
C	Spill opens	12 deg approx before TDC
D	Fuel valve closes	16 deg approx ATDC
E	Reflected pressure wave due to fuel valve closing	
F	Partial equilibrium	20 deg approx
G	Injection period	
P_R	Residual fuel pressure	
$\Delta P/\Delta\alpha$	Rate of fuel pressure rise before fuel valve opens	2.5 approx
FP_0	Fuel valve opening pressure	350 kg cm²
αP_0	Angle at which fuel valve opens relative to TDC	4 deg approx BTDC
FP_{MAX}	Maximum fuel pump discharge pressure	650 kg cm²

FIG. 2 Typical trace of fuel pressure at approximately full power

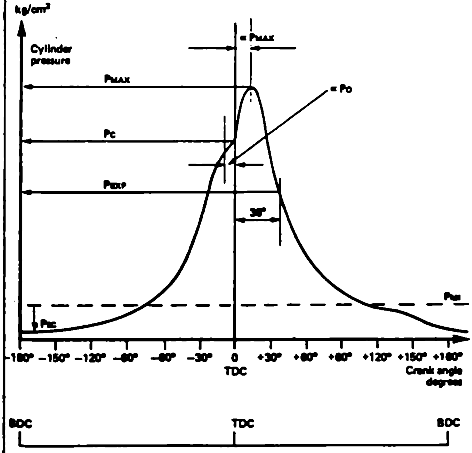


FIG. 3 Typical trace of cylinder pressure at approximately full power

BDC	Bottom dead centre	
TDC	Top dead centre	
SO	Scavenge ports open	142.5 deg approx. ATDC
SC	Scavenge ports close	142.5 deg approx. BTDC
FVO	Fuel valve opens	4 deg approx. BTDC
EO	Exhaust opens	. . . deg ATDC
EC	Exhaust closes	. . . deg BTDC

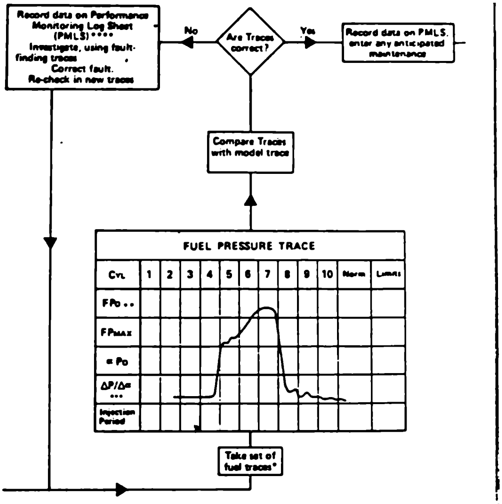
hile taking traces, the fuel system should e suitably 'locked' to remove governor influence and so achieve steady running nditions.

• The dynamic opening pressure of a fuel alve in service will be nearly 100 kg cm^2 igher than the static opening pressure on e test bench. This is due to inertia in the oving parts of the fuel valve.

•• $\Delta P/\Delta\alpha$ (rate of injection-pressure rise) nd injection period will have to be measured by scale drawing from a Polaroid picure of trace.

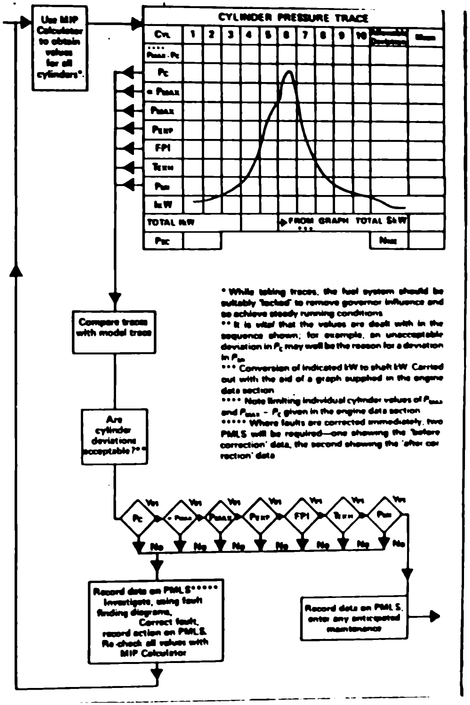
••• Where faults are corrected mmediately, two PMLS will be required: ne showing the 'before-correction' data, e second showing the 'after-correction' ata

IG. 3 Pre-performance check



FAULTS	INDICATION $\frac{\Delta P}{\Delta \alpha}$ LOW	FPo LOW	FPo HIGH	Pmax HIGH	Pmax LOW	αPo EARLY	αPo LATE	Injection period LONG	Injection period SHORT	Reflected pressure wave DAMPED
Worn fuel pump internals	▨				▨		░		░	░
Leaking valve on fuel pump	▨				▨		░		░	░
Fuel valve spring set too HIGH			▨				░		░	
Fuel valve spring set too LOW or broken		▨				░		░		
Fuel valve nozzle worn excessively or damaged					▨					
Fuel pump index setting too HIGH				▨				░		
Fuel pump index setting too LOW					▨					
Choked fuel valve nozzle				░						
Fuel pump timing too ADVANCED (LEAD)										
Fuel pump timing too RETARDED (LEAD)										
Fuel viscosity too HIGH				▨						
Fuel viscosity too LOW					░					

FIG. 4 Pre-performance check: fault-finding table



* While taking traces, the fuel system should be suitably 'locked' to remove governor influence and to achieve steady running conditions

** It is vital that the values are dealt with in the sequence shown; for example, an unacceptable deviation in P_c may well be the reason for a deviation in P_{m}

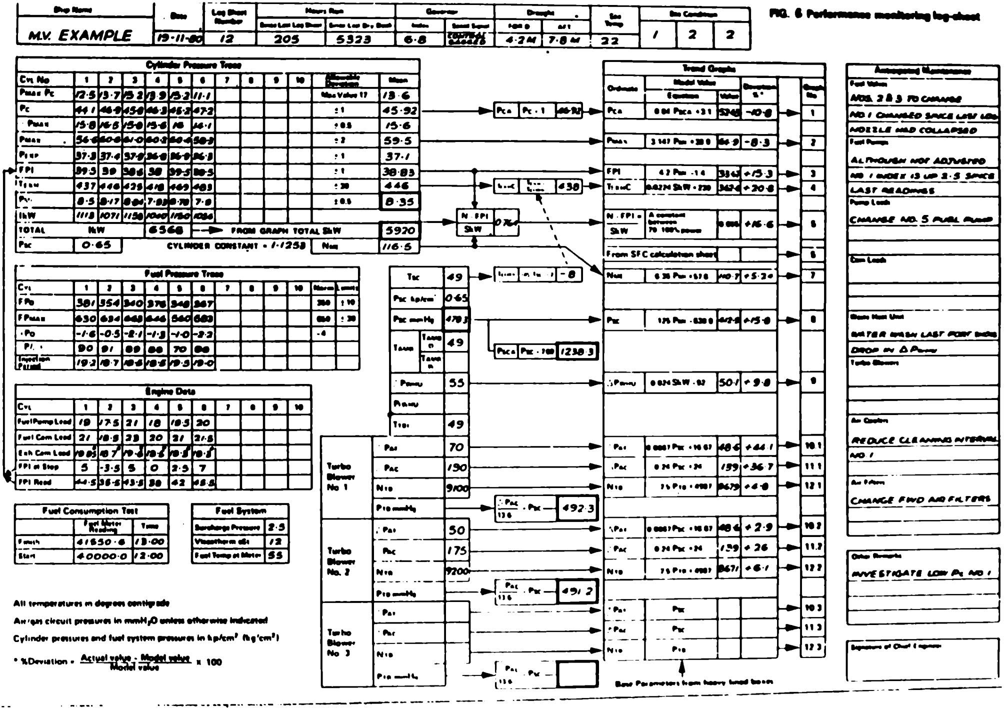
*** Conversion of indicated kW to shaft kW. Carried out with the aid of a graph supplied in the engine data section

**** Note limiting individual cylinder values of P_{max} and $P_{max} - P_c$ given in the engine data section

***** Where faults are corrected immediately, two PMLS will be required—one showing the 'before correction' data, the second showing the 'after correction' data

FIG 5 Performance check ▶

FIG. 6 Performance monitoring log-sheet



Ship Name	Date	Log Sheet Number	Hours Run: Since Last Log Sheet	Hours Run: Since Last Dry Dock	Governor: Index	Governor: Speed Setting	Draught: FORD	Draught: AFT	Sea Temp	Sea Conditions		
M.V. EXAMPLE	19-11-80	12	205	5323	6·8	[illegible]	4·2M	7·8M	22	1	2	2

Cylinder Pressure Trace

Cyl No	1	2	3	4	5	6	7	8	9	10	Allowable Deviation	Mean
Pmax-Pc	12·5	13·7	15·2	13·9	15·2	11·1					Max Value 17	13·6
Pc	44·1	46·9	45·8	46·3	45·2	47·2					±1	45·92
ΔPmax	15·8	16·6	15·8	15·6	16	14·1					±0·5	15·6
Pmax	56·6	60·6	61·0	60·2	60·4	58·3					±2	59·5
Pexp	37·3	37·4	37·8	36·8	36·9	36·3					±1	37·1
FPI	39·5	39	38·6	38	39·5	38·5					±1	38·83
Texh	437	446	428	418	469	483					±30	446
Pi	8·5	8·17	8·84	7·83	8·70	7·8					±0·5	8·35
IkW	1113	1071	1158	1040	1150	1036						
TOTAL	IkW		6568	→ FROM GRAPH TOTAL ShW								5920
Psc	0·65		CYLINDER CONSTANT = 1·1258								Nex	116·5

Fuel Pressure Trace

Cyl	1	2	3	4	5	6	7	8	9	10	Norm	Limits
FPo	381	354	340	376	348	367					350	±10
FPmax	630	634	648	646	560	683					650	±30
ΔPo	-1·6	-0·5	-2·1	-1·3	-1·0	-2·2					-4	
Pl	90	91	89	88	70	88						
Injection Period	19·2	18·7	18·6	18·6	19·5	19·0						

Engine Data

Cyl	1	2	3	4	5	6	7	8	9	10
Fuel Pump Lead	19	17·5	21	18	18·5	20				
Fuel Cam Lead	21	18·5	23	20	21	21·5				
Exh Cam Lead	19·85	18·7	19·8	19·8	19·8	19·8				
FPI at Stop	5	-3·5	5	0	2·5	7				
FPI Read	44·5	36·5	43·5	38	42	45·5				

Fuel Consumption Test

	Fuel Meter Reading	Time
Finish	41650·6	13·00
Start	40000·0	12·00

Fuel System

Surcharge Pressure	2·5
Viscotherm cSt	12
Fuel Temp at Meter	55

Tsc	49
Psc kp/cm²	0·65
Psc mmHg	478·3
Tamb in	49
Tamb out	
ΔPaircooler	55
Paircooler	
Tsc	49

Turbo Blower No 1	ΔPat	70
	ΔPac	190
	Ntb	9100
	Ptb mmHg	
Turbo Blower No. 2	ΔPat	50
	ΔPac	175
	Ntb	9200
	Ptb mmHg	
Turbo Blower No 3	ΔPat	
	ΔPac	
	Ntb	
	Ptb mmHg	

Pca = Pc + 1 → 46·92

Texh C = Texh − Tamb → 438

N · FPI / ShW → 0·764

Tsc − Tamb in → −8

Psca = Psc + 760 → 1238·3

ΔPac/13·6 + Psc → 492·3

ΔPac/13·6 + Psc → 491·2

ΔPac/13·6 + Psc →

Trend Graphs

Ordinate	Model Value: Equation	Model Value: Value	Deviation %*	Graph No
Pca	0·04 Psca + 3·1	52·6	−10·8	1
Pmax	3·147 Pm + 33·0	64·9	−8·3	2
FPI	4·2 Pm − 1·4	33·6	+15·3	3
Texh C	0·0274 ShW + 230	362·6	+20·8	4
N · FPI / ShW =	A constant between 70 100% power	0·655	+16·6	5
From SFC calculation sheet				6
Nex	0·36 Pm + 67·8	110·7	+5·24	7
Psc	1·75 Pm − 830·0	412·5	+15·8	8
ΔPaircooler	0·024 ShW − 92	50·1	+9·8	9
ΔPat	0·0087 Pac + 16·07	48·6	+44·1	10.1
ΔPac	0·24 Pac + 24	139	+36·7	11.1
Ntb	7·5 Ptb + 4987	8679	+4·8	12.1
ΔPat	0·0087 Pac + 16·07	48·6	+2·9	10.2
ΔPac	0·24 Pac + 24	139	+26	11.2
Ntb	7·5 Ptb + 4987	8671	+6·1	12.2
ΔPat	Pac			10.3
ΔPac	Pac			11.3
Ntb	Ptb			12.3

Base Parameters from heavy load bases

Anticipated Maintenance

Fuel Valves

NOS. 2 & 3 TO CHANGE

NO 1 CHANGED SINCE LAST LOG

NOZZLE HAD COLLAPSED

Fuel Pumps

ALTHOUGH NOT ADJUSTED

NO 1 INDEX IS UP 2·5 SINCE

LAST READINGS

Pump Leads

CHANGE NO. 5 FUEL PUMP

Cam Leads

Waste Heat Unit

WATER WASH LAST PORT BOILER

DROP IN Δ Pwhu

Turbo Blowers

Air Coolers

REDUCE CLEANING INTERVAL

NO. 1

Air Filters

CHANGE FWD AIR FILTERS

Other Remarks

INVESTIGATE LOW Pc NO 1

Signature of Chief Engineer

All temperatures in degrees centigrade

Air/gas circuit pressures in mmH₂O unless otherwise indicated

Cylinder pressures and fuel system pressures in kp/cm² (kg/cm²)

$$\text{* \%Deviation} = \frac{\text{Actual value} - \text{Model value}}{\text{Model value}} \times 100$$

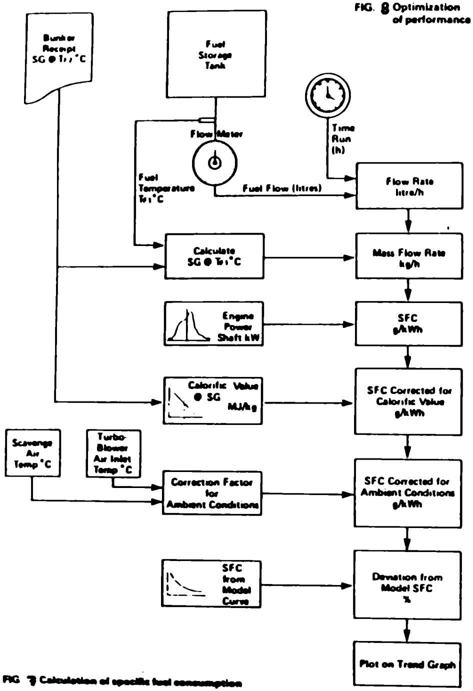
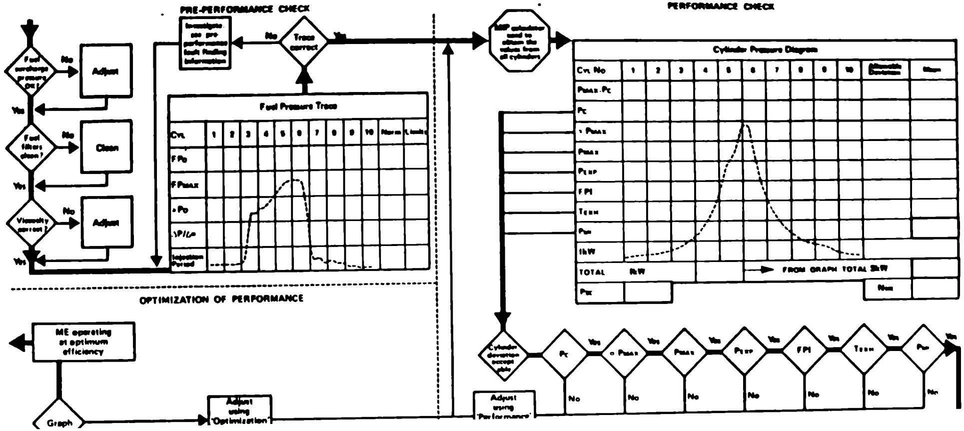


FIG 7 Calculation of specific fuel consumption

FIG. 8 Optimization of performance ▶

CURVES	1	2	3	4	5	6	7	8	9	10	11	12	
BASE	P_{CA}	P_{mi}	P_{mi}	ShW	ShW	ShW	P_{mi}	P_{mi}	ShW	P_{sc}	P_{sc}	P_{te}	
ORDINATE	P_{CA}	P_{max}	FPI	T_{exhc}	$\frac{N_t(FPI)}{ShW}$	SFC	N_{tc}	P_{sc}	ΔP_{filter}	ΔP_{af}	ΔP_{ac}	N_{tc}	
Defective: Exh V/Vs. Sulzer rand V/Vs, piston rings and crown. Worn liner. Choked scavenge ports.	◢			◤									
Decreased ship resistance due to reduced draught.		◢					◤						
Increased ship resistance due to fouled hull and/or damaged propeller.		◤					◢						
Dirty or damaged turbine/compressor.		◢		◤				◢		◢			
Coking in turbine nozzle ring.								◤					
Fuel pump plunger worn. Leaky suction valve.			◤										
Air cooler fouled on water side.				◤									
Air cooler fouled on air side.		◢		◤							◤	◤	
Air filter fouled.		◢		◤						◤	◢	◤	
Retarded fuel injection timing		◢											
Advanced fuel injection timing		◤											
Waste heat unit fouled.									◤			◤	
Retarded exhaust valve cam timing.								◢					


PRE-PERFORMANCE CHECK
Fuel surcharge pressure OK?
No
Adjust
Yes
Fuel filters clean?
No
Clean
Yes
Viscosity correct?
No
Adjust
Yes
Investigate, see pre-performance fault finding information
No
Trace correct
Yes
Fuel Pressure Trace
CYL
1 2 3 4 5 6 7 8 9 10
Norm
Limits
F Po
F Pmax
Po
ΔP/Δα
Injection Period
OPTIMIZATION OF PERFORMANCE
ME operating at optimum efficiency
Graph
Adjust using 'Optimization'
PERFORMANCE CHECK
MIP calculator used to obtain the values from all cylinders
Cylinder Pressure Diagram
CYL No
1 2 3 4 5 6 7 8 9 10
Allowable Deviation
Mean
Pmax-Pc
Pc
α Pmax
Pmax
Pexp
FPI
Texh
Pmi
ihW
TOTAL ihW
FROM GRAPH TOTAL ShW
Psc
Nme
Cylinder deviation acceptable
Pc
α Pmax
Pmax
Pexp
FPI
Texh
Pmi
Yes
No
Adjust using 'Performance'

6.0 Torsion meter

A torsion meter is an instrument which utilizes the fact that a rotating shaft, which transfers energy from, for example, a diesel engine to a propeller, is distorted by the torque to which it is exposed.

Gauge principles; a great variety of gauge principles have been used for torque meter design. Two different basic principles have been used; one involves measuring the torsion over a certain shaft length with some form of displacement gauge, the other is based upon direct measurement of stress or strain in a short section of the shaft.

6.1 Significance of installing torsion meter on board ship

The significance of installing a torsion meter on board ships is:

1. to provide continous measurement of the torque transmitted to a ship's propeller, shaft speed, and power on the shaft drives, which will be a good means to engineers to avoid overloading the main engine;
2. to provide a good means for determining main engine mechanical performance such as mechanical efficiency and lubrication efficiency;
3. to provide a means for calculating an accurate value of fuel consumption per unit of power hour;
4. it will provide an accurate means to determine the degree of ship hull fouling;
5. it provides an accurate means to assist in determining the minimum fuel consumption per unit of power hour at the desired ship speed, by varying engine revs and/or propeller pitch.

CHAPTER IV

An efficient spares control system is vital to shipboard maintenance system. A planned maintenance system requires adequate spares at the right time, if it is to be successful. Conversely, it is impossible to estimate which spares to order in advance and in what number, unless maintenance is planned.

1.0 Objectives

The objectives of a spares control system are;

1. to ensure that the right amount of spares are held aboard ship; and
2. to ensure the availability of spares, when required.

These objectives are interrelated since the choice of which spares to carry and in what number depends on what spares will be required.

2.0 Development of spares control system

During a development stage of spares control system the first move is to take an inventory of all the spares requirements and their consumption rates. This information must come mainly from knowledge of the ship in question and her equipment, from the manufacturer's recommendation, records of maintenance system used, experience with similar equipment, classification society requirements, and spare control system being installed in the concerned ships. However, it is necessary to take an inventory of the spares already held on board.

2.1 Creation of spares policy statement

The spares policy statement should basically lay down what spares are to be included in the system, how many to be held in stock aboard ship and when to reorder.

Since the level of any individual item held in stock will fluctuate as it is used and reordered, it is necessary to determine the maximum, minimum and reorder stock levels. Taking into consideration the following factors:

- the demand of the maintenance system;
- the risks and subsequent costs of a break down, which might need the spares items in question to rectify it;
- the use rate;
- the time interval between the ship ordering and receiving the item;
- the cost and availability abroad; and
- voyage length and availability of alternatives.

It is necessary to mention that the policy statement may not, in the final system, appear as a separate document. It could very well be incorporated into the structure of the spares records or take the form of a spares manual.

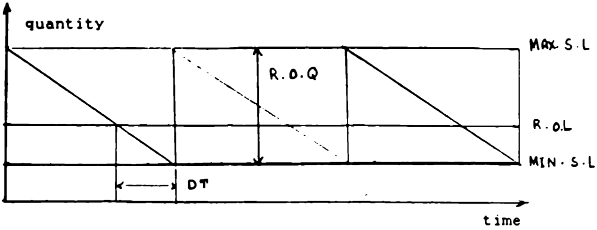
Once the above mentioned levels are made absolutely clear to shipboard personnel and the technical department, there should be no credibility gap between the two.

The policy statement must also clearly identify each spares item with regard to its use and for the purposes of recording. This is usually done by the use of codes. Such a codification should be built on.

- a spares ordering code built in the policy statement;
- manufacturer's own codes;
- drawings, manuals, and plate number; and
- location in the engine room.

The above mentioned will ensure the right way of using spares, but one system of coding should be relied on during communication between the ship staff and shore side during the reordering. This will minimize the errors and ambiguities.

2.2 Stockholding theory.



Delivery time (D.T)

Reorder quantity (R.O.Q).
The reorder quantity represents the difference between the maximum and minimum number of parts in stock.

Maximum stock level (MAX.S.L)
The maximum stock level is the greatest number of parts that should be in stock at any time.

The reorder level (R.O.L)
The reorder level is the level at which new parts must be ordered, if the number of items in stock is not to fall below the minimum stock level before the ordered items are received.

Minimum stock level; (MIN.S.L)
The minimum stock level is the minimum stock quantity that can be accepted. It represents the buffer that is necessary in order to avoid shortages.

3.0 Operational stage of spares control system

1. Spares records; it is essential that all spares movements are recorded. These records must be kept up to date and the information they contain should be readily available. It makes the job of reordering and controlling stock much easier for shipboard personnel if the relevant information from the policy statement is incorporated per item, into these records.

They should also show, per item, present stock levels and outstanding orders to be delivered, preferably with dates of orders.

A duplicate records for each ship should also be held ashore and be updated.

2. Order/receipt/issue documentaion.
Spares documentation flow systems within the ship to shore channel often roughly passes the following.

The technical department orders spares from the manufacturers, to the fleet's requirements, and directs them to the ships. Together with these spares go the necessary identifying documentation, e.g. packing and receipt notes.

The ship will normally acknowledge receipt by returning the checking receipt notes and will record the delivered spares in the spares records. Faulty spares, etc. should, where possible, be returned, each spares item should also be readily identifiable, say by a tag attached to it, on arrival at the ship and during storage aboard.

As spares are issued from the ship's store, tags from the spares used should be collected, delivering them periodically to the concerned engineer. Alternatively the engineer may make a check with the amount of spares consumed, which are registered in the maintenance work reports.

In any event, the engineers record the usage of spares in the spares records and, when the reorder level is reached on any item, the appropriate number should be ordered to bring the level of stock back to the maximum.

3. Store keeping

In addition to the above mentioned, spares items should be stored so that they remain in good condition (dry, secured, protected, etc.). Ensuring that the shipboard stores are secure, all items should be stowed so that they can be easily retrieved when required. This calls for careful planning of storage space, especially when this space is limited.

Periodic inventories should be carried out to assure that the actual stock levels agree with the records. The responsible engineer must ensure that the correct spares are issued for each job. (17,18)

CHAPTER V

1.0 Fuel system operating practice

One of the major problems facing chief engineers when taking bunkers is the uncertainty of the quality of the fuel supplied, let alone the difficulty in determining the precise quantity of fuel delivered to their vessels.

Therefore the operator should be more aware of these problems and should give to his shipboard operators additional support by placing his vessel on fuel testing programmes, both the shore based type of service and on board testing facility.

By providing on board fuel testing facility, the ship operator knows a little more of the general characteristics of the fuel; he can then apply the correct storage heating, optimize his treatment plant and ensure accurate pre-combustion heating. This approach undoubtedly reduces the risk of some of the more common problems. (12)

1.1 Bunkering

The chief engineers should always take their five litres fuel oil sample during bunkering operations and retain this for future comparison and possible claims. This is in addition to the oil supplier's retained sample. Both these samples should be clearly marked and kept on board for three months after all the fuel has been used.

Undoubtedly, the key to accurate fuel analysis is representative sampling. Hence it is advisable that sampling takes place throughout the entire bunkering operation.

There are several methods of obtaining samples in addition to the above mentioned method. The most efficient is by means of a flow meter and sample pump. It is recommended that the sampling procedures set out by the various organisations should be well studied and observed in practice of every vessel bunkering. (12)

1.2 Operating practice with high pour point fuels.

During bunkering it is advisable to note if the delivery temperature is high. This can be an indication of a high pour point fuel. When high wax content fuels are suspected, it is recommended to test the pour point of the fuel. Armed with the knowledge of a high pour point fuel, then the temperature of fuel in the double bottom tanks and/or other storage tanks can be kept at least 5°C above the pour point temperature. Obviously it is important in these circumstances that transfer lines are effectively drained.

Once a high pour point fuel solidifies, it is virtually impossible to reheat the fuel sufficiently to liquify a whole storage tank. Addition of gas oils or diesel oils does not lower the pour point to any effective level, hence the importance of heating capacity and its correct application is emphasized. (12)

1.3 Fuel oil segregation during storage.

Experience has demonstrated the importance of adapting the segregation of fuel oils of different bunkering supplies and sources in order to avoid incompatibility and unstable mixes.

When an unstable or slightly unstable fuel is mixed with other fuels, the mix is considered incompatible if a large amount of sludge type sediment is precipitated; this is particularly evident during the centrifugal separation process. This is basically when the two fuels have different predominating hydrocarbon groups and the resulting mixture becomes unstable and is unable to keep the asphaltenes in suspension owing to the changed carbon/hydrogen ratio.

Mild forms of instability have been observed in settling and service tanks when the blend equilibrium is unstable, causing layering or stratification of the oil according to the densities of the individual components. This occurrence has been detected by sudden variations in the viscosity/temperature controls in the engine fuel system.

Thermal instability occurs in some fuels when sludge is formed as a result of high temperature heating (140 C pre-combustion fuel temperature). This is especially noted with some cracked fuels where the sludge formation is aggravated by heating and oxidation and quite often depends on the degree of thermal cracking that has been carried out in the refinery.

In severe cases, the asphaltence content of the mixture may drop out of suspension as a carbonaceous sludge, the fuel oils concerned being regarded as imcompatible. It is normally first noticed when overloading of the separator equipment occurs owing to large amounts of sludge being deposited in the separator bowl. The biggest danger in these circumstances is for the sludge to be carried over into the main engine. The presence of sludge in the combustion chamber will obviously prolong ignition and increase thermal loading on the cylinder liner surfaces, causing loss of the cylinder lubrication film and, ultimately, serious engine damage. (12)

1.4 Settling tank

As the viscosities and densities of the fuel oils in use at sea are increasing, these fuels are becoming slightly more difficult to treat. The separation of water and foreign matter from fuel in settling tanks is of course a slow process, and in practice the speed at which the contaminations separate out depends not only on the differences in density but also on particle and droplet size together with the viscosity of the bulk of the fuel.

An average size water droplet will take approximately 24 hours to fall a distance of 1 m in an IF180 fuel at 50° C, and the ideal tank, from this point of view, would be a long tank of minimal height. However, this is not possible in practice. The settling process is the main safeguard against gross water contamination of fuel and provides a buffer tank for the separation process. Therefore, it is vital that the practice of checking for water in engine room tanks is strictly adhered to; settling tank temperatures should be kept as high as possible, within the flash point limitations. (12)

1.5 Fuel oil treatment by centrifugal separation

It is quite clear that there is no substitute for efficient centrifugal separation of heavy fuel oil for the removal of water and particulate contaminants and in minimizing engine wear rates. Centrifuging is basically a greatly accelerated settling process where the available time for separation, which depends on machine capacity and actual throughput, is very small. Ideally, the total flow through the centrifuge should be just sufficient to match the engine consumption, thus requiring continuous centrifuging. This will maximize the dwell time of the fuel passing through the separator.

Homogenizers have been mentioned as possible replacements for the separator on the basis of being more cost effective, as they actually pass all the fuel to the main engine, apparently in a fine form, including the sludge which is normally removed by the separator. However, trials and research have shown that piston ring and cylinder liner wear rates may increase about fourfould when using homogenizers in place of centrifugal separators.

The centrifuge is undoubtedly the most efficient way to remove most of the particles, always supposing that the equipment is properly set up, operated and maintained. When assessing fuel incidents, more problems relate to incorrect operation of centrifuge than any other aspects of fuel handling, which reinforces the view that this equipment is the key to successful operation of diesel engines on heavy fuel oil. The preferred arrangement of a multi- separator installation, two in parallel as purifiers followed by a third machine in a series with the former, but operating as a clarifier has proved to be the most efficient way of separation, of the order of 80 to 90 % contaminant removal.

When operating the separator as a purifier there are two continuous outlets, one for the lighter fuel oil phase and the other for the heavy water phase; the sludge and solid particles are normally retained in the separator bowl for intermittent discharge.

Operating the centrifuge as a clarifier involves basically only one continous outlet for clean oil. The water outlet is effectively sealed off by use of the smallest diameter gravity disc available. Thus the clarifier is for removal of finer solid particles and sludge, giving up to 10 % additional cleaning effect.

From the above mentioned, the operating staff must pay close attention to the related operating instructions for each particular machine, together with the more specific recommendations for maintainance and troubleshooting and that can be achieved through the appropriate maintenance system. The main problem feared by operators is the occurrence of incompatible fuel mixes, as discussed earlier. Such problems show themselves in the early stages of separating fuel drawn from a new tank and, if not quickly checked, result in overloading of separators, and ultimately mechanical damage of main engine.

In these extreme circumstances, parallel operation of purifiers is preferred with reduced throughput. No attempt should be made to double purify using series operation, since this tends to aggravate the process, causing excessive amounts of sludge to be produced. One approach used for early indication of potential trouble is sampling and testing of the fuel bunkers and fuel system generally. More specifically, on board testing allows an early assessment of separator efficiency and effictiveness. This may be done by sampling at purifier inlets and outlets and checking for water content and presence of abrasive particles. Batch testing of the viscosity and density of fuel before the separator provides further assistance for correct operation. (12)

Regarding the removal of abrasive particles, including catalytic fines, most of the larger particles (over 5 to 10 macron size) can be removed by correct operation of well maintained separators being run in the preferred configuration. However, many ships operating do not have the luxury of three separators; the next best arrangement is two machines either in parallel as purifiers, or in series as purifier and clarifier, as shown by the following table.

Parallel or series	"Normal service" spot tests 1 or 2 water content less than 1 % Density below 0.990 kg/L at 15 C
Parallel	"Abnormal condition" spot tests 3, 4 or 5 water content above 1 % Density above 0.990 kg/L at 15 C
Series	"Abnormal conditions" If catalystic fines suspected in bunkered fuel.

(1.6) Fuel heating

Care must be taken to ensure that the correct amount of heating is applied. Some fuels have been shown to be thermally unstable as well as chemically unstable and heating merely accelerated the process of sludge precipitation in an unstable fuel.

Vigilance is needed to check the buildup of sludge and carbon deposits on heating surfaces, particularly following fluctuations in heating requirements. Two things can aggravate this problem, one is double heating by recirculation, causing sludge formation as well as the raising of the service tank temperature to levels which may exceed the fuel's flash point. Also, viscosity increases can result from evaporation of the more volatile fuel components. A further cause of heating surface fouling is the reduction of flow to such an extent that the fuel oil heating surface interface is overheated. This eventually reduces heater efficiency and effectiveness. (12)

1.7 Fuel combustion

To ensure the correct atomization and spray pattern when fuel is injected into each cylinder, the fuel must first be heated to the recommended injection viscosity. It is always worthwhile checking the viscotherm setting periodically, to make certain that the correct injection viscosity is being achieved.

The particle size of the fuel injection spare is of course influenced by the injection viscosity and, in addition to combustion problem, small increases in fuel viscosity tend to increase the loading on the injection pump drive shaft, gear and camfaces. Excessively high viscosity can also increase the risk of fuel impingement on the piston crown and cylinder wall. Too low a viscosity leads to incomplete combustion. Hence, the control of correct injection temperature cannot be overemphasized.

Higher carbon fuels on the marine market today generally have higher specific gravity and slower burning characteristics. If injection timing is not controlled and adjusted, preferably automatically, after burning can occur in extreme cases when the lubricated surfaces of the cylinder liners would be exposed and oil film overheated. This would result in the pistons and exhaust valve becoming overheated. Extremely accelerated ring wear, and eventually liner cracking, can result under these conditions. (12)

2.0 Fuel oil quality control

Marine fuel oils will increasingly be the product of secondary refining processes such as breaking and catalytic cracking, which, combined with the wide range of crude oils available and the effects of blending two or more different oils to provide the final product, result in a wide variation in characteristics between individual consignments.

Ideally, each bunker consignment should be accompanied by a detailed delivery of the type recommended by the International Chamber of Shipping (ICS). But the (ICS) bunker delivery note has not found general acceptance and fuels are usually supplied with only the minimum of information.

The international standards of petroleum fuels for marine oil engines and boilers such as British Standard BSMA100 & ISO Standard may clarify the situation somewhat. However, even where bunkers are supplied in accordance with the specifications laid down, it must be remembered that except for flash point the values quoted are maxima, and the limitations imposed by engine manufacturers or the fuel-oil system may not match any of the combinations of characteristics for the classes given. (12)

3.0 On board fuel oil testing

In the current situation it is obviously necessary to monitor the quality of the fuels supplied. This need has been partly met by the laboratory based analysis services offered by a number of organizations, of which the fuel oil bunker analysis and advisory service (FOBAS) of LLoyd's Register of Shipping is one. The tests give the information necessary for bunker purchasers to check the quality of a fuel and for the ship's staff to handle the fuel in the most appropriate manner. While the analysis results will normally be available before the fuel from a particular bunkering is used, the time taken in transporting samples to the laboratory and in actual analysis precludes this information being immediately available to those on board.

In spite of possible problems with incompatibility between different fuel consignments, it is often operationally necessary that fuels be mixed on board. In these instances the characteristics of the resulting fuel will be a factor of the original values and the quantities involved, and can only be determined by on board tests. Also, once fuel oil is loaded, it can be subject to layering or contamination which is best identified by on board testing.

To meet the increasing awareness of the importance of assessing fuel oil characteristics as a key to the successful treatment of marine fuel oils, a number of companies have produced test kits which are intended to give fairly quickly on the spot results. (12,8)

3.1 Test selection

In selecting which on board tests are to be carried out, the end purpose must be kept in mind. It would be counter-productive to include ill conceived tests which produce unreliable results. If bunker suppliers are to be challenged regarding the quality of the fuel supplied or if operational settings are to be made on the basis of the results obtained, it is essential that there be a reasonable degree of confidence in the value determined. At present the test available for viscosity, density, pourpoint, water content and compatibility would appear to be the only tests which even come near to satisfying these requirements. (12)

3.2 Interpretation of test results

Analysis is only the first step toward the successful storage, handling and use of fuel oils and should not be seen as an end in itself. The information derived from testing either in a laboratory or on board can only be of value if the significance of the characteristics determined can be appreciated with regard to the likely problems and remedies possible. Testing must therefore be backed up by a comprehensive education and training programme in order to give those on board a sound understanding of current fuel oil practice. (8)

4.0 Fuel additives

There are two distinct categories of additives, namely those which assist in reducing potential problems in precombustion and those which react during the post combustion phase.

The precombustion phase covers the period from receipt of the fuel on board, up to the time that it is otomised in a burner or an injector, thus the period covers storage on board and the shipboard treatment of the fuel. An effective additive for this phase should be able to make a positive contribution to the following aspects.

- Dispersion of possible sludge in the fuel tanks.
- Promotion of separation of any dispersed water within the fuel.
- Prevention of potential polymerisation and sludge formation.
- Prevention of corrosion within the fuel lines and tanks.

During the past combustion phase the potential areas of concern depend upon the category of plant installed.

In order to reduce the problems that may occur in the post combustion phase an additive which has the effect of an ash modifier may under certain circumstances be beneficial. Hence, the ash modifier should have the ability to increase the melting point temperature and make the ash more fireable. By increasing the melting point, the temperature may reach a point when the ash is not in a molten form and will not be corrosive. In being more fireable the ash is less likely to stick to metal surfaces and effect heat transfer.

Some additives are termed "combustion catalysts". The function of the combustion catalyst is to cause the carbon to be more extensively burnt, and inhibit the formation of carbon precursors.

Not all combustion problems can be solved by the use of fuel oil treatment; some can be resolved by mechanical means while some are in fact caused by engine design and simply cannot be curved.

The benefit of using fuel additives is very difficult to measure in terms of cost effectiveness without setting up expensive measurement and testing procedures. The advice on whether or not an additive is working and increasing vessel efficiency is the subsequent report that can be gotten from competent ship board engineers.

It is claimed that fuel additives do work and do improve fuel efficiency and vessel performance, but not every time or in all cases. Their use has to be constantly checked against need, cost and bunker quality, in association with regular shore side analysis of the fuel being used. (8)

5.0 Fuel consumption measurement

Fuel consumption measurement on ships has never been good and the present state of the art is far from ideal, with most systems having some chance of error.

The first essential requirement for accurate measurement is that the fuel consumed by the engine is measured directly by a single meter. Measuring the fuel consumed by subtracting the return flow rate from that supplied involves errors in calculating fuel consumption. (12)

CHAPTER VI

1.0 Study example based on planned maintenance system.

With reference to the basic elements required in planned maintenance mentioned in Chapter 3, Section 3, the study example illustrates the step of identification of machinery which deserves to be included in the planned maintenance system, by dividing the machinery into main groups and sections identified with their individual code, as it is illustrated in point 1 & 2 under this study example.

Whereas the assessment of what maintenance is to be carried out is referred to in the instruction manual i.e. under this study example the instruction manuals are MAN-B&W edition 38 A and 7 A, which should be listed in the job requirement card.

With respect to the above mentioned, the determination of frequency of carrying out particular maintenance is referred to in the same instruction manual edition E 7, section 900-1. However, there are some other factors that should be indicated such as survey cycle maximum length, relationship between calender time and running hours, number of units in each set of machine and the time intervals required for the control function. But to avoid a large number of papers to cover these aspects, it is just mentioned herein.

Point 3 is an example to show partly the running hours section in terms of coding and model of forms that can be used for recording the running hours.

Finally, the last two papers under this study example show the work done report form layout comprising all necessary data required.

1. Dividing the machinery into main groups identified with their individual code.

Details of main groups	Main group	Machine number
Main diesel engine	A	
Turbo charger	B	
Propeller and shafting	C	
Auxiliary diesel engine	D	
Emergency diesel generator engine	E	
Air compressor	F	
Centrifuge/purifier	G	
Boiler, exhaust gas economiser	H	
Heat exchanger	I	
Fresh water generator, evaporator	J	
Steering gear and rudder assembly	K	
Refrigerator	L	
Air conditioning	M	
Cargo pump	N	
Pump	O	
Control equipment	P	
Deck machinery	R	
Oily water separator	S	
Inert gas system	T	
Safety equipment	U	

2. Dividing the main group into section if necessary

M/V M E No 1	A	1					
Code identification Title of section	Main group	Machine No	Section	Section	Section	Sub section	Page No
Running hours	A	1	0	0	0		
Checking and maintenance programme	A	1	9	0	0		
Cylinder cover	A	1	9	0	1		
Piston with Rod and stuffing box	A	1	9	0	3		
Cylinder-liner and cylinder lubrication	A	1	9	0	2		
Cross head with connecting rod	A	1	9	0	3		
Crank shaft, thrust bearing & turning gear	A	1	9	0	5		
Mechanical control gear	A	1	9	0	6		
Starting air system	A	1	9	0	7		
Exhaust valve	A	1	9	0	8		
Fuel oil system	A	1	9	0	9		
Turbo charge system	A	1	9	1	0		
Safety equipment	A	1	9	1	1		
Assembly or large parts	A	1	9	1	2		
General tools	A	1	9	1	3		

3. Running hours

Running hours Section	A	1	0	0	0	
Code identification Information		MachNo	Sec	Sec	Sec	Sub set
Main engine	A	1	0	0	0	0
Cylinder covers	A	1	1	0	0	0
Cylinder cover No 1	A	1	1	0	0	
Fuel valve No 1	A	1	1	0	1	1
Starting air valve No 1	A	1	1	0	2	1
Safety valve No 1	A	1	1	0	3	1

<table>
<tr><td>A</td><td>1</td><td>0</td><td>0</td><td>0</td><td colspan="4">Total running hours of M E.</td></tr>
<tr><td colspan="5">month
Information</td><td>Jan</td><td>Feb</td><td>Mar</td><td>Apr</td></tr>
<tr><td rowspan="2">Year</td><td colspan="4">Running hours/month</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Total running hours</td><td></td><td></td><td></td><td></td></tr>
</table>

<table>
<tr><td>A</td><td>1</td><td>1</td><td>0</td><td>0</td><td>1</td><td colspan="3">Cylinder cover running hours</td></tr>
<tr><td colspan="5">month
Information</td><td>Jan</td><td>Feb</td><td>Mar</td><td>Apr</td></tr>
<tr><td rowspan="2">Year</td><td colspan="4">Running hours/month</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Running hours since last overhaul</td><td></td><td></td><td></td><td></td></tr>
</table>

A	1	9	0	1	Cylinder cover. Job requirement card

Number of working men		Time required to execute the job	

Spares need	Code	Location in E. R.
References		
Tools need	Code	Location in E. R.

Work done report 1

M/V		Number of working men	
Date		Total working hours	
Item		Working hours since last overhaul	
Code		Job carried out by	

Reason

Results

Remedy

Data of measurement according to instruction

Comments on procedures used

Work done report 2			
Spares consumed	Code	Quantity	
		Remaining	Consumed
Tools used condition			

2.0 An application example on pre-performance check.

1. Fig (1) shows a superimposed ideal fuel pressure trace on a defective fuel pressure trace. According to this basis, certain faults can be identified and certain data can be extracted by measurement. These data should be recorded on a performance monitoring log sheet for further investigation.

2. Fig (2) shows a real set of fuel pressure traces, been taken according to a certain instruction, at a specified load (fuel setting), for a certain engine.
The traces were compared with an ideal traces depicting the fuel pressure at that load, for further investigation.
Some of the required data are measured up to scale. Results are written below each trace.

3. Data of each fuel pressure trace is recorded on a data table from the (PMLS) as shown in Table (1). Investigation of the measurement results can be conducted as follows:

- Find out the differences between the normal value and measured value for each parameter. If the differences are within the limits, data can be recorded on the main performance monitoring log sheet and any further anticipated maintenance can be entered on the same sheet. See (Chapter III, section 5, Figure (6)).
- If the differences are not within the limits, investigation by using fault finding traces, and performance check-fault finding table listed in Chapter III, Section (5), Figure (4) can be conducted, e.g.
- Fuel valve opening pressure (FPO).
  Cyl. No. 1, 2, 3, 4, 5 fuel valve spring set too high.
  Cyl. No. 6 fuel valve spring set too low.
- Maximum fuel pump discharge pressure FPMAX.
  Cyl. No. 3, 2 are within the acceptable limit

Cyl. No. 1, 5 are within the acceptable limit but check is required;
fuel viscosity should not be too low, fuel pump index setting should not be too low. If these are as required, maintenance can be anticipated as follows;
fuel valve noizzle slightly worn out or slightly damaged, leaking fuel valve on fuel pump, slightly worn out fuel pump internals. One or more reasons have to be condemned, and through further investigation the exact reason may be detected.
Cyl. No. 4, 6 maintenance is required and can be conducted as follows; check fuel valve, replace if it is necessary. This action can be supported by a check on rate of pressure rise to make sure that the fuel pump internals are not effected. Check on reflected pressure wave due to fuel valve closing action to make sure that valve on the fuel pump is not leaking.
If this is not the case, the required maintenance should be conducted on the fuel pump, either to replace the pump valve or the pump internals. The right action can be coordinated with the latest trace results.
N.B. It is necessary that the pre-performance check results are investigated, and reasons for faults are remedied before any further action concerning cylinder pressure condition is taken except taking traces for the purpose of improving judgement.

2.1 An application example on performance check.
1. Fig. (3) shows a superimposed ideal trace of cylinder pressure on a defected cylinder pressure trace. According to this basis certain faults can be identified and certain data can be extracted by measurement. These data should be recorded on performance monitoring log sheet for further investigation.

2. Fig. (4) shows a real set of cylinder pressure traces which have been taken according to a certain instruction, at a

specified load (full setting), for a certain engine. The traces were compared with an ideal trace depicting the cylinder pressure at that load, for further investigation.
Some of the required data are measured up to scale. Results are written below each trace.

3. By recording data of each cylinder pressure trace on a data table from the (PMLS), as shown in Table (2), investigation of the measurement results can be conducted as follows:

- Find out the mean value for each parameter through the six cylinder readings, allowable deviation for each parameter, total IKW, and SKW from the concerned graph.
- It is vital that the values are dealt with in sequence shown in (Chapter III, Section 5, Figure 5).For example an unacceptable deviation in PC may be the reason for a deviation in PMI.
- If the deviation for each parameter is acceptable, data can be recorded on main performance log sheet, and any further anticipated maintenance can be entered on the same sheet (refer to Fig. 6, (Chapter III, Section 5).

  If the deviations are not acceptable, investigation can be conducted using fault finding traces and the fault finding tables, which are most often provided in the engine maker's instruction manuals.

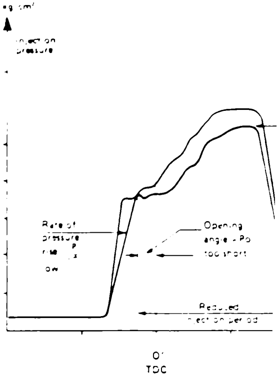
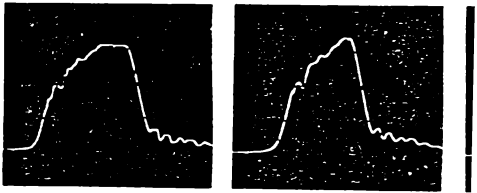


FIG 4 Effects on fuel-pressure curve of worn fuel-pump internals, leaking valve on fuel pump

INDICATIONS
Reduced maximum fuel pressure
Low rate of pressure rise
Reduced injection period
Opening angle before TDC too short
Reflecting pressure wave damped

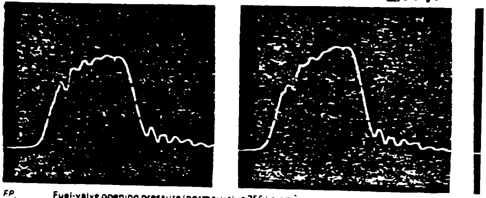


NO 1 CYLINDER
FP_0 400 kg cm^2
αP_0 1.1 deg BTDC
FP_{MAX} 619 kg cm^2

NO 2 CYLINDER
FP_0 416 kg cm^2
αP_0 0.4 deg ATDC
FP_{MAX} - 672 kg cm^2

NO 4 CYLINDER
FP_0 400 kg cm^2
αP_0 0.5 deg BTDC
FP_{MAX} 556 kg cm^2

NO 5 CYLINDER
FP_0 393 kg cm^2
αP_0 0.5 deg BTDC
FP_{MAX} 610 kg cm^2



FP_0	Fuel-valve opening pressure (normal value 350 kg cm^2)
αP_0	Angle at which fuel valve opens relative to TDC (normal value 4 deg BTDC)
FP_{MAX}	Maximum fuel-pump discharge pressure (normal value 650 kg cm^2)

FIG. 2 Polaroid photographs of fuel-pressure trac

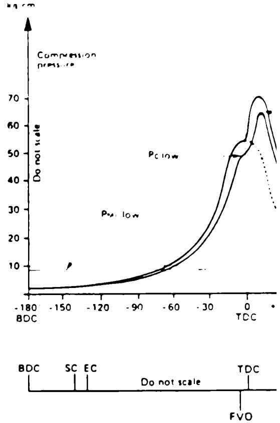
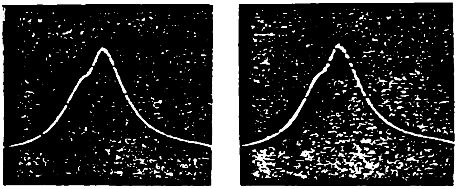


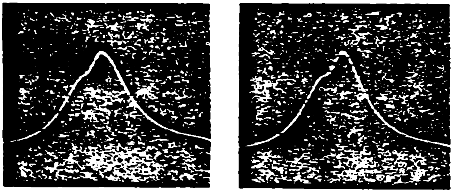
FIG 3 Effects on pressure curve of worn or defective piston rings burnt piston crown worn liner

INDICATIONS
Compression pressure (P_c) low
Maximum pressure (P_{max}) low
Expansion pressure (P_{exp}) low
Mean indicated pressure (P_{mi}) low



NO 1 CYLINDER
P_w 9 00 kg cm^2
P_{max} 57 30 kg cm^2
P_c 44 3 kg cm^2
αP_{max} 15 6 deg
P_{exp} 37 8 kg cm^2
T_{exh} 449 C
P_{sc} 0 65 kg cm^2
N_{eng} 117 rev min
Power 1184 kW
FPI 44

NO 2 CYLINDER
P_w 8 38 kg cm^2
P_{max} 60 00 kg cm^2
P_c 46 0 kg cm^2
αP_{max} 16 5 deg
P_{exp} 38 5 kg cm^2
T_{exh} 435 C
P_{sc} 0 65 kg cm^2
N_{eng} 117 rev min
Power 1103 kW
FPI 36



NO 4 CYLINDER
P_w 8 45 kg cm^2
P_{max} 60 50 kg cm^2
P_c 45 5 kg cm^2
αP_{max} 15 3 deg
P_{exp} 36 80 kg cm^2
T_{exh} 431 C
P_{sc} 0 65 kg cm^2
N_{eng} 117 rev min
Power [illegible] kW
FPI 39

NO 5 CYLINDER
P_w 8 75 kg cm^2
P_{max} 62 50 kg cm^2
P_c 46 8 kg cm^2
αP_{max} 15 8 deg
P_{exp} 38 20 kg cm^2
T_{exh} 444 C
P_{sc} 0 65 kg cm^2
N_{eng} 117 rev min
Power 1151 kW
FPI 47

▲ FIG. 4 Polaroid photographs of combustion

Table (1) of performance monitoring log sheet

Fuel pressure trace								
Cyl.	1	2	3	4	5	6	Norm	Limits
FPO	400	416	380	400	393	322	350	± 10
FP Max α Po	619 - 1.1	672 - 0.4	660 - 1.2	556 - 0.5	610 - 0.5	593 - 4.4	650 - 4	± 30 -
$\Delta P/\Delta\alpha$	-	-	-	-	-	-	-	-
Inject. period	-	-	-	-	-	-	-	-

Table (2) of performance monitoring log sheet

Cylinder pressure trace								
Cyl.	1	2	3	4	5	6	Allowable Deviation	Mean
P max-Pc	13.00	14.00	15.30	15.00	15.70	15.80	Max v. 17	14.8
PC	44.30	46.0	45.7	45.5	46.80	44.60	± 1	45.48
α Pmax	15.6	16.5	15.8	15.3	15.8	14.4	± 0.5	15.56
Pmax	57.30	60.0	61.00	60.50	62.50	60.40	± 2	60.28
Pexp	37.8	38.50	38.70	36.80	38.20	36.20	± 1	37.7
FPI	39	39.5	39	39	39.3	37	± 1	41.5
TEXH	449°C	435°C	425°C	431°C	444°C	449°C	± 20	438.83
PMI	9.00	8.38	9.00	8.45	8.75	8.45	± 0.5	8.67
IKW	1184	1103	1184	1112	1151	1112		1141
Total IKW	6846	From graph	Total SKW					---
PSC	0.65						NME	117 R.P.M

Engine data reference

FPI at stop	5	-3.5	5	0	2.7	7
FPI Read	44	36	44	39	42	44

3.0 Operator experience with vibration monitoring.

To demonstrate the practice of vibration analysis as a diagnostic tool, the following case histories are presented. Each case history depicts a different method of vibration analysis. They were selected to demonstrate the variety of diagnostic paths available based upon the data gathered and the instrumentation utilized. In each case, significant financial savings were realized by pinpointing and identifying problems before major unit failure. All operating characteristics of a particular machine must be known in order to identify areas from which harmful vibration amplitudes may originate. Machinery description is an essential element of the analytic process. (4)

3.1 Vibration analysis utilizing an x-y signature plot.

Figure (1) is a signature plot of the female lobe bearing of a rotary compressor. The unit was operating below capacity and making excessive noise. A shoreside team was called in to take a signature plot.

Machinery ID - Rotary air compressor.

- Speeds: male lobe shaft - 1800 CPM cycle per minute.
- Female lobe shaft - 1200 CPM.
- Teeth: male lobe - 4.
- Teeth: female lobe - 6.
- Shaft bearings - Angular contact ball bearings.
- Number of balls/bearing - 12.

Instrumentation:

- IRD model 350 vibration analyzer with x-y recorder.
- Velocity pickup with magnetic mount.
- Frequency range of plot 500-500,000 CPM.
- Amplitude range of plot 0.0-1.0 in/sec.

Analysis:

(1) Broad band filter out readings were excessive in the vertical and horizontal directions.
(2) Major vibration amplitudes were appearing at 60.000 CPM with significant peaks at 17,000; 14,000; and 7,500 CPM.

Conclusions:

The major amplitude at 60,000 CPM was caused by improper meshing of the male and female lobe teeth. When the unit was opened up for inspection, the lobes of the male and female rotors were found to be damaged. The harmonic pattern would work out as follows:

(a) The 6 lobe rotor shows up first at approximately 7,500 CPM since 6 lobes x 1,200 CPM = 7,200 CPM.
(b) The 4 lobe rotor coincides with this since 4 lobes x 1,800 CPM = 7,200
(c) The predominant frequency of 60.000 CPM is the eighth harmonic of 7.200 CPM.

Corrective action:

The faulty lobe rotors were replaced. (4)

3.2 Vibration analysis using a hand held tunable filter meter

Figure (2) is a representative sample of monthly vibration readings (unfiltered) for a ship's service turbo generator. The unit was operating satisfactorily, but the chief engineer was concerned with the increase in vibration amplitude at test point no. 1, the end bearing. Since the shipboard meter was equipped with a filter, the chief engineer used it to determine that the predominant frequency was at 9,200 CPM, which is the rotating speed of the turbine shaft.

Machinery ID: ship's service turbo generator.

- Speed: turbine shaft 9,200 CPM.
- Generator shaft - 3,600 CPM.
- Shaft bearings: sleeve type journal bearing.
- Number: 6.

Instrumentation:

- IRD model 320 vibration selector with tunable filter velocity transducer pick up with magnetic mount.

Analysis:

(1) Filter out readings for bearing/test point no. 1 were above normal.

(2) By using the tunable filter, the ship's staff determined the predominant vibration frequency to be equal to the rotating speed of the turbine. Since the other test points were normal, the chief engineer decided to open and inspect the no. 1 bearing assembly.
The inspection revealed excessive clearance in the thrust ring color plate which is adjacent to the bearing.

Conclusion:

The mechanical looseness of the thrust plate caused an exitation of the No 1 bearing.

Corrective action:

The thrust plate was renewed on 05 June 1981. Note that the vibration readings taken on that date after repairs had been made indicate a dramatic improvement in the vibration signature of the machine (4).

3.3 Vibration analysis demonstrating external environmental vibration

Environmental vibration is vibration with a source other than operation of the machine or unit on which it is observed. Figure (3) is a shipboard example of vibration readings taken on a main sea water circulating pump.
When the readings were first taken, the chief engineer became alarmed at the level of unfiltered vibration at test point No 3, the top motor bearing. He utilized a filter to determine that the predominant frequency was approximately 500 CPM while underway, but was approximately 700 CPM while in port.

Machinery ID: Main sea water circulating pump
. capacity 29 cub. meters
. motor HP: 60
. shaft speed: 700 CPM

Instrumentation:

- IRD Model 320 vibration selector with tunable filter velocity transducer pick-up with magnetic mount.

Analysis:

(1) The unfiltered vibration readings at test point No 3 increased from 0.3 in/sec in port to 0.5 - 0.7 in/sec underway at 104 shaft CPM.
(2) By use of the tunable filter, the ship's staff discovered that the predominant frequency underway was 500 CPMs which was equal to the blade passing frequency of the main propeller. In port, the predominant frequency of 700 CPM was equal to the speed of the machine.

Conclusion:

- The increase in vibration while underway was caused by externally exited environmental vibrations generated by the propeller (4).

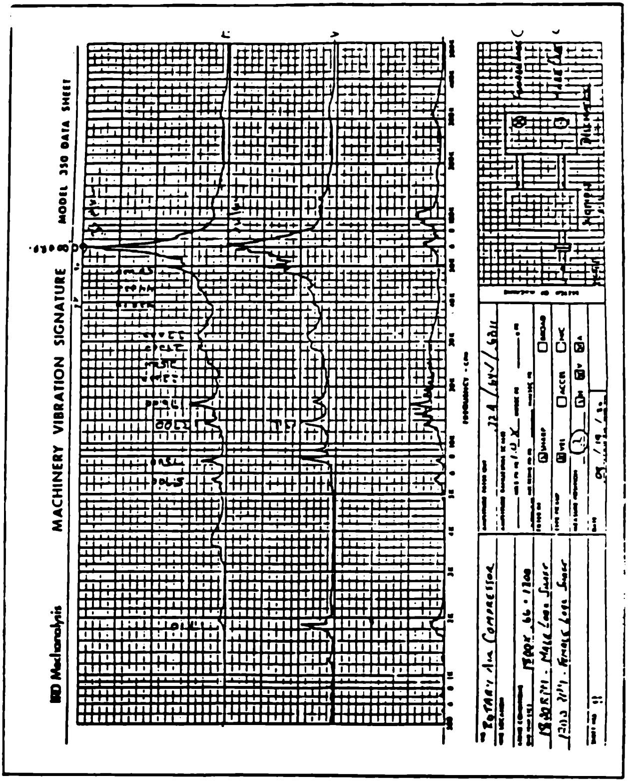
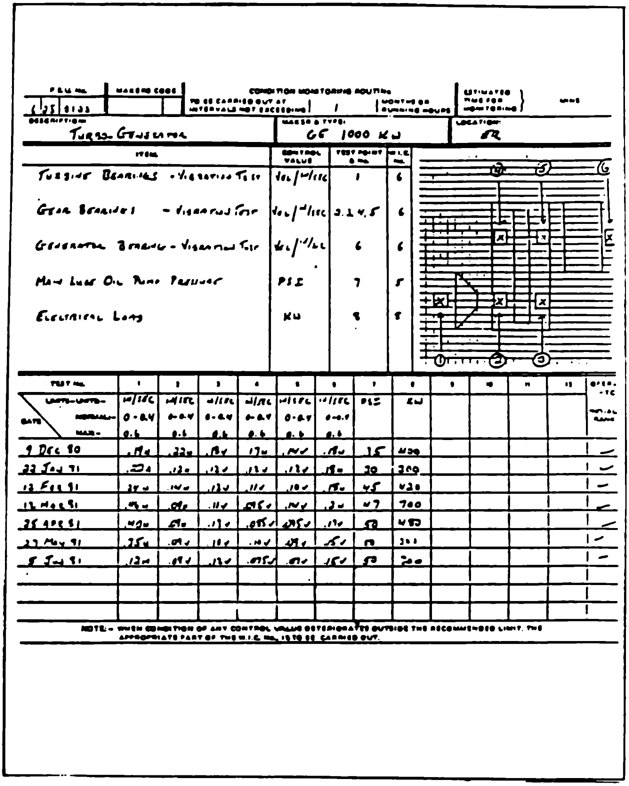


Figure 4 Signature Plot



P.M.S. No.	MAKERS CODE	CONDITION MONITORING ROUTINE			ESTIMATED TIME FOR MONITORING	
1 25 3133		TO BE CARRIED OUT AT INTERVALS NOT EXCEEDING	1	MONTHS OR RUNNING HOURS		MINS

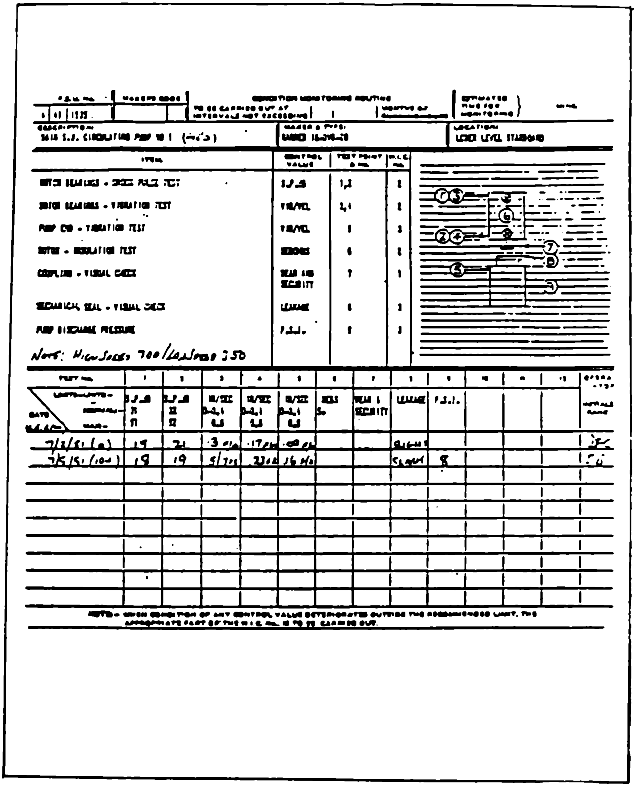
DESCRIPTION:	MAKER & TYPE:	LOCATION:
Turbo-Generator	GE 1000 KW	ER

ITEM	CONTROL VALUE	TEST POINT No.	W.I.C. No.
Turbine Bearings - Vibration Test	Vel/in/sec	1	6
Gear Bearings - Vibration Test	Vel/in/sec	2.3.4.5	6
Generator Bearing - Vibration Test	Vel/in/sec	6	6
Main Lube Oil Pump Pressure	PSI	7	5
Electrical Load	KW	8	8

TEST No.	1	2	3	4	5	6	7	8	9	10	11	12	OPER-ATE
UNITS-LIMITS	in/sec	in/sec	in/sec	in/sec	in/sec	in/sec	PSI	KW					NORMAL RANGE
NORMAL	0-0.4	0-0.4	0-0.4	0-0.4	0-0.4	0-0.4							
DATE MAX.	0.6	0.6	0.6	0.6	0.6	0.6							
9 Dec 90	.18H	.22H	.18V	17H	.14V	.18H	35	430					—
22 Jan 91	.20A	.12H	.13V	.13V	.13V	.18H	30	300					—
13 Feb 91	24H	.14H	.13V	.11V	.10V	.15H	45	420					—
13 Mar 91	[illegible]	.09H	.11V	.095V	.14V	.20H	47	700					—
25 Apr 91	.42H	50H	.13V	.055V	.055V	.13V	50	450					—
27 May 91	.25H	.09V	.10V	.10V	[illegible]	.15V	50	301					—
5 Jun 91	.12H	.09V	.13V	.075V	.07V	.15V	50	200					—

NOTE:- WHEN CONDITION OF ANY CONTROL VALUE DETERIORATES OUTSIDE THE RECOMMENDED LIMIT, THE APPROPRIATE PART OF THE W.I.C. No. IS TO BE CARRIED OUT.

Figure 2 Vibration (Unfiltered)



CONDITION MONITORING ROUTINE

TO BE CARRIED OUT AT INTERVALS NOT EXCEEDING 1

DESCRIPTION: S.W. CIRCULATING PUMP NO 1

MAKER & TYPE:

LOCATION: LOWER LEVEL STARBOARD

ITEM	CONTROL VALUE	TEST POINT No.	W.I.C. No.
MOTOR BEARINGS - SHOCK PULSE TEST	S.P.M.	1,2	2
MOTOR BEARINGS - VIBRATION TEST	VIB/VEL	3,4	2
PUMP END - VIBRATION TEST	VIB/VEL	5	3
MOTOR - INSULATION TEST	MEGOHMS	6	2
COUPLING - VISUAL CHECK	WEAR AND SECURITY	7	1
MECHANICAL SEAL - VISUAL CHECK	LEAKAGE	8	3
PUMP DISCHARGE PRESSURE	P.S.I.	9	3

Note: High Speed 700/Low Speed 350

TEST No.	1	2	3	4	5	6	7	8	9	10	11	12	OPERATOR
UNITS	S.P.M.	S.P.M.	IN/SEC	IN/SEC	IN/SEC	MEGS	WEAR & SECURITY	LEAKAGE	P.S.I.				INITIALS
7/8/81 (LO)	19	21	.3 in/s	.17 in/s	.09 in/s			Slight					
7/15/81 (HI)	19	19	.5 in/s	.23 in/s	.16 in/s			Slight	8				

NOTE - WHEN CONDITION OF ANY CONTROL VALUE DETERIORATES OUTSIDE THE RECOMMENDED LIMIT, THE APPROPRIATE PART OF THE W.I.C. No. IS TO BE CARRIED OUT.

Figure 3 Circulating Water Pump Vibration

CHAPTER VII

1.0 Conclusion

In pursuing a balanced maintenance system it is necessary to design a scheme which will unite planned maintenance, corrective maintenance and condition based maintenance in a coherent plan fitted with the operating constraints of the vessel. The overall aim is to prevent failure and improve the availability of ship's machinery.

Planned maintenance can do much to achieve high reliability, but the cost will be rather more replacements than would be necessary if the failures are allowed to occur.
Too frequent maintenance may also contribute to unnecessary loss of availability, and may even make the maintenance situation worse by introducing additional faults.

Condition monitoring cannot eliminate the maintenance work, but by foretelling the failures it can make it possible to plan the preventive work into scheduled downtime. This should lead to higher working efficiency and hence some saving of labour costs.

There are several approaches to condition monitoring. They are not mutually exclusive, A condition based maintenance system will require a mixture of two or more of them. Therefore it is essential to find or develop condition monitoring methods which can provide sufficient leadtime to permit orderly management of maintenance.

- Vibration analysis techniques can predict changes and impending failures before they become serious or even disastrous. Furthermore, subsequent analysis of the vibration enables its sources to be located without dismantling a machine or structure.

Although vibration analysis is not a panacea for all engineering problems, it can be an exceptionally useful aid for solving and removing most of them.

- Experience with use of the performance monitoring system has shown that the efficiency of operation of marine diesel engines can be improved, and engine moving parts condition can be reflected. Simultaneously with use of torsion meter as a means for shaft power calculation, a worthwhile contribution to an energy-conservation programme can be achieved.

- Shorebased laboratory results for lub oil analysis can play an important part in the successful condition monitoring for machinery internal condition.

- A well designed and organized spare parts and stock control policy is important when failures are prevented by the use of a preventive maintenance system.

- An efficient fuel oil treatment system, assisted by shore based and onboard fuel oil testing programme, appropriate fuel oil consumption measuring equipment, and appropriate fuel oil additive are very important to ensure that a good quality of fuel is burnt in the diesel engine.

2.0 Recommendation

1. For new ships

. Every new ship should be provided with the following:-

. Planned maintenance and spare parts control system, together with the required documentation such as job card, feed back reports, etc. It should be easy to operate, based on similarity to the system that will be used.

. Condition monitoring

a) Among protection systems for main engine, condition monitoring should be comprised of piston ring wear monitoring system, and thermal load monitoring system, performance monitoring system, if possible with necessary software describing the trend graph equations, engine specifications, mathematical model of the engine, including the effects on performance of outside influences such as ambient temperature, fuel specific energy value, etc. The output from the computer could be displayed in terms of percentage deviations, trend graphs, and specific fuel consumption.

b) Sample analysis system; for lubrication oils of machinery and rotating machinery vibration. The external vibration and internal vibration signature should be taken during seatrials for the purpose of base line reference signature.

. Torsion meter as a means for calculating shaft horse power for the purpose of mechanical evaluation and overload protection provided with an on-line ship performance monitoring system will help to match the engine load, engine RPM, ship's trim and weather condition together at a minimum fuel consumption, when ships are fitted with fixed pitch propellers. Propeller pitch, engine RPM, ship's speed, ship's trim and weather condition together at a minimum fuel consumption when ships are fitted with variable pitch propellers.

. Universal characteristic curves depicting the ideal relationship between the following parameter changes; propeller load, engine RPM, ship's speed, fuel consumption, propeller efficiency and engine efficiency within the main engine load limit. However, these will provide means for validation of main engine condition, and ship's underwater hull condition.

. An efficient fuel oil treatment system with a minimum number of three purifiers, provided with onboard fuel testing equipment, supplemented with the shore based fuel analysis programme.

2.2 For existing ships:

For every ship it is necessary to do the following:
. inventory of spares, tools on board;
. inventory of instruction manuals, drawing and arrange to supply the missing;
. revise technical records to extrapolate failure modes and machinery being exposed to;
. survey the fuel and lubrication oil treatment system efficiency and quantify the required installation cost;
. survey the fuel consumption measurement system reliability for use;
. quantify the cost of providing each ship with:
. on-line ship performance monitoring system;
. torsion meter and engine performance monitoring system;
. establishment of planned maintenance;
. vibration measurement intrument, and use of consultant to implement vibration analysis as a condition monitoring exclusively for rotating machines;
. piston ring wear monitoring and thermal load monitoring systems

Once the above mentioned are achieved, ships can be treated as follows:
. All ships should have an efficient fuel and lubrication treatment system with a minimum number of two fuel oil purifiers.
. All ships should have a reliable fuel measurement system.

- To follow a policy that will compromise between preventive maintenance and corrective maintenance possibility costs as far as the failure risk and consequential cost is concerned.
- To establish spare parts and stock control policy for each ship.

It should be noted that fault diagnostic instrumentation alone, no matter how advanced or sophisticated, will not give the direct answer to a problem. Even the most expensive equipment in the wrong hands could be virtually impotent. Therefore, it is necessary to establish up-dating courses for both ship and shore staff in the following areas:

- fuel handling,
- maintenance management,
- ship machinery development,
- computer technology,
- vibration analysis, and
- hydraulic systems handling and maintenance

GLOSSARY

Analyzer. An analyzer is an instrument that decomposes a time varying signal into its frequency components.

Background Noise. Background noise is the total of all interference in a system used for the production, detection, measurement, or recording of a signal which exists independently of the presence of the signal.

Barred range. A range of rotational speeds over which continuous operation is to be avoided because of large torsional vibratory stress.

Blending. Blending is intimate mixing of the various components in the preparation of a product of specified properties.

Broad-Band Vibration. Broad-band vibration is vibration having frequency components distributed over a broad frequency band.

Catalyst. Catalyst is a substance used to accelerate or retard chemical change without itself undergoing significant change.

Catalyst Fines. Catalyst fines are small (typically less than 50 micron) particles of catalyst aluminium silicate which may be present in residues from a catalytic cracking plant.

Carbonaceous. Carbonaceous is an organic matter.

Compatibility. Compatibility means, when blending two or more fuels from different crude origins or refinery processes, great care must be taken that resultant blend is a homogenous mixture in which asphaltenes remain in stable equilibrium i.e. in suspension. If resultant fuel precipitates asphaltenes, the components are incompatible.

Cracking. Cracking is a conversion of molecular structure of a fuel to provide lighter oils from heavier, carried out either directly by heat and pressure (thermal) or in presence of catalyst (catalytic).

Critical speed. Critical speed is a speed of a rotating system at which a resonant frequency of the system is excited.

Cycle. A cycle is one of a series of complete sequence of events which repeat at regular intervals.

Damping. Damping is the dissipation of energy with time or distance.

Diluent. Diluent means, in fuel oil blending, low viscosity materials having suitably high flash points used to reduce the viscosities of residues.

Excitation. Excitation is an external force (or other input) applied to a system that causes the system to respond.

Filter. A filter is a device for separating waves on the basis of their frequency. It introduces relatively small insertion loss to waves in one or more frequency bands and relatively large insertion loss to waves of other frequencies.

Harmonic. A harmonic is a sinusoidal function with a frequency which is an integral multiple of the fundamental frequency.

Harmonic Analysis. Harmonic analysis is the process by which the amplitude and phase of the harmonics of a vibration are determined.

Heptane. Heptane is an alkaline hydrocarbon.

Narrow-band Vibration. Narrow-band vibration is vibration having frequency components only within a narrow-band. It has the appearance of a sine wave whose amplitude varies in an unpredictable manner.

Noise. Noise is any undesired signal. By extension, noise is any unwanted disturbance within a useful frequency band such as undesired electric waves in a transmission channel or device.

Order. Order is the frequency of a vibration divided by speed.

Oscillation. Oscillation is the variation, usually with time, above and below a mean value.

Oxidation. Oxidation is the reaction of a substance with oxygen.

Peak-to-peak value. The peak-to-peak value of vibrating quantity is the algebraic difference between the extremes of the quantity.

Period. Period is the interval of time required for a periodic motion or phenomenon to complete a cycle or repeat itself.

Polymerisation. Polymerisation is the combination of several molecules to form a more complex molecule having the same empirical formula as the simpler ones. It is often a reversible process.

Resonance. Resonance of a system in forced vibration exists when a small change in excitation frequency causes a reduction in response to the system.

Response. The response of a device or system is the motion (or other output) resulting from an excitation (stimulus) under specified conditions.

Residue. Residue is the material remaining as an unevaporated liquid (or solid) from a process involving destillation or cracking.

Signature. The signature of a machine or system is the vibration patterns which characterizes it. The baseline signature is that which characterizes the machine when it is new or in its best working condition.

Spectro-chemical Analysis. Any of a number of techniques using spectrometric measurements to determine the presence and/or concentration of elemental or molecular constituents in a sample.

Thermal cracking (visbreaking). A cracking process in which the reaction is prompted purely by the action of heat and pressure.

Transducer (Pickup). A transducer is a device which converts shock or vibratory motion into an optical, mechanical, or, most commonly, electrical signal which is proportional to a physical parameter of the motion.

V I T (Variable Injection Timing).

Vibration. Vibration is any periodic or random oscillation of a mechanical system.

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